THE MICROSCOPE

ITS DESIGN, CONSTRUCTION AND APPLICATIONS

A SYMPOSIUM AND GENERAL DISCUSSION BY MANY AUTHORITIES

(See Overleaf)

EDITED BY

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A SYMPOSIUM AND GENERAL DISCUSSION

HELD BY

The Faraday Society
The Royal Microscopical Society
The Optical Society
The Photomicrographic Society

IN CO-OPERATION WITH

The Technical Optics Committee of the British Science Guild

WEDNESDAY, JANUARY 14th, 1920

IN THE

ROOMS OF THE ROYAL SOCIETY, LONDON.

[By kind permission of the President and Council]

Including Reports of adjourned Discussions held in Sheffield, February 24th, and in London, April 21st, 1920.

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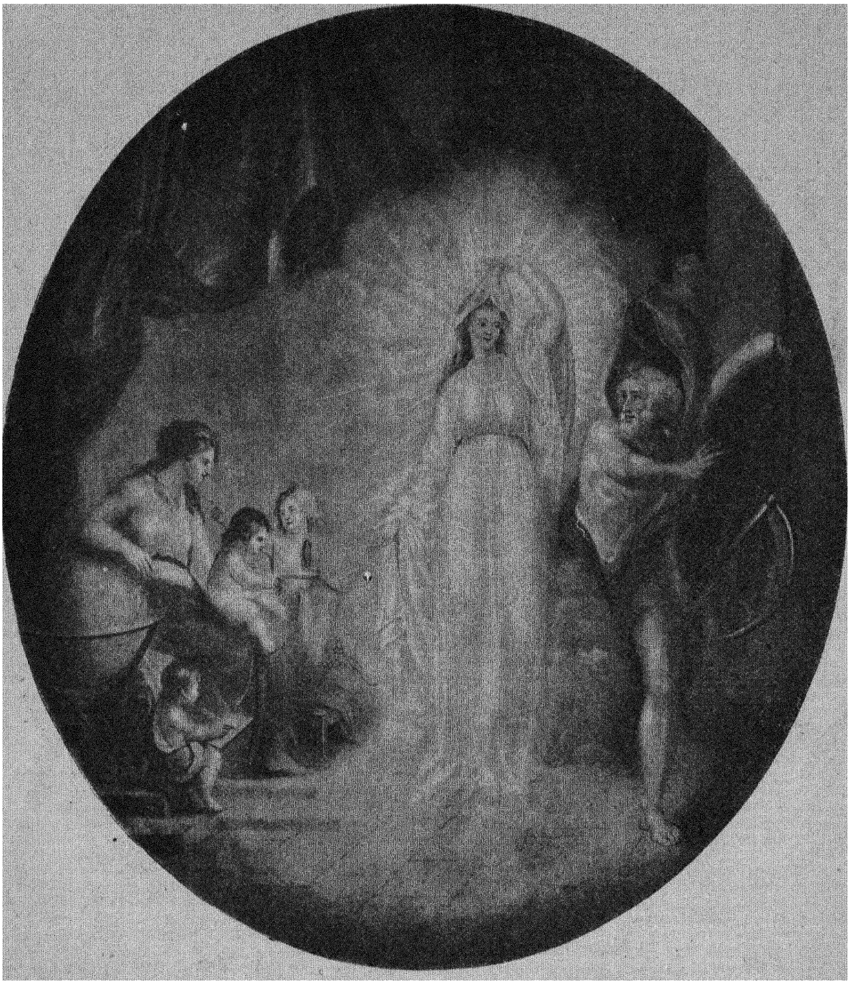

Truth discovering to Time, Science instructing her Children in the Improvements on the Microscope.

London Published July 1st 1787, by Geo. Adams. No 60 Fleet Street.

This Illustration is taken from the Book by George Adams.
"ESSAYS ON THE MICROSCOPE."
Printed in the year 1798.

A
SYMPOSIUM AND GENERAL DISCUSSION
ON
THE MICROSCOPE:
Its Design, Construction, and Applications.

THE FARADAY SOCIETY, the ROYAL MICROSCOPICAL SOCIETY, the OPTICAL SOCIETY, and the PHOTOMICROGRAPHIC SOCIETY in co-operation with the Technical Optics Committee of the BRITISH SCIENCE GUILD, meeting in joint session, held a Symposium and General Discussion on "THE MICROSCOPE: ITS DESIGN, CONSTRUCTION AND APPLICATIONS," on Wednesday, January 14th, 1920, in the Rooms of the Royal Society at Burlington House, Piccadilly, London, by kind permission of the President and Council.

The purpose of the Symposium and Discussion, which was organised by a Joint Committee of the Co-operating Societies, at the initiative of Sir Robert Hadfield, Bart., was:—

(1) To stimulate the study of and research in microscopical science in the United Kingdom by indicating lines of progress in the mechanical and optical design of the instrument, showing by means of exhibits recent improvements in the

microscope and its technique and the varied uses to which the microscope can be applied as an instrument of research in the sciences, arts and industries.

(2) To encourage the manufacture in this country of the highest class of instrument and of the optical glass required for that purpose.

The meeting extended over two sessions: from 4.15 to 6.30 and from 8.15 to 10.30 p.m. The exhibition, which was probably the most important of its kind ever held in this country, took place during the afternoon preceding the meeting, in the Library of the Royal Society. The list of exhibits is printed as an Appendix to this Report.

The total attendance at the exhibition and meeting was not far short of one thousand, and the proceedings throughout were of an enthusiastic nature.

The meeting was presided over by **Sir Robert Hadfield, Bart., D.Sc., D.Met., F.R.S.**, President of *The Faraday Society*, supported by **Mr. J. E. Barnard**, President of the *Royal Microscopical Society*, **Professor F. J. Cheshire, C.B.E.**, President of the *Optical Society*, **Mr. F. Martin Duncan**, President of the *Photomicrographic Society*, and **Dr. R. Mullineux Walmsley**, Chairman of the *Technical Optics Committee of the British Science Guild.*

The CHAIRMAN, **Sir Robert Hadfield**, opened the proceedings with the following remarks:—

Whilst we must not congratulate ourselves too soon, we can at any rate say, by the large numbers present, by the extraordinary variety and number of valuable papers submitted, by the exhibits, both historical and modern, also by the interest shown generally, that this Symposium is going to aid in throwing more light on the important subjects with which it is attempting to deal.

I earnestly hope, as I am sure we all do, that as a result of our proceedings, not only will our knowledge—and knowledge is power—be increased, but that this country will be rendered independent of foreign supplies in products which it is so vital should be made at home. In this respect I should like to read a valuable letter I have received from that public-spirited and broad-minded citizen Lord Burnham, who is taking great interest in our deliberations and who had hoped to be present. In his letter he is kind enough to say:—

"It is, as you say, of vast importance to our future that we should do all we can to assist the British optical industry to meet foreign competition and to strike out new lines of advance for itself. We all know how far we were left behind in the days before the war and this time it is up to us to make good once for all.

I wish I could come myself, but I am deeply engaged on that day. It is a great thing that you and your colleagues should put yourselves at the head of such a movement."

I think we all feel stimulated by such encouraging words from a man like Lord Burnham, who, while not a scientist or technician, sees the great importance of this movement.

It is also a great satisfaction to find so many well-known representatives of science and technology taking part in our Symposium to-day. America has contributed several valuable communications, including those of Prof. Sauveur, who has done so much for the microscope and metallography, Dr. Zay Jeffries, who has made the subject of grain size peculiarly his own, and others.

We have important communications from France and Italy in the papers of Monsieur Eugene Schneider, Prof. H. le Chatelier, Signor Giolitti, and others.

As regards our own country, I venture to say that the host of Addresses and Papers, some forty in all, are unique, and of a most valuable nature. The Addresses include those to be presented by Sir Herbert Jackson, Mr. Barnard, Prof. Cheshire, and Prof. Conrady, each of them meriting commendation of the highest kind. As regards the authors of the large number of papers presented, it is not possible to mention here the names, for they are so numerous, but it can be added that the general standard of the papers is exceedingly high, and we thank those many contributors most heartily for the trouble and pains they have taken in preparing their communications.

May I say, too, on your behalf, how extremely grateful we are to the authors of the Addresses and Papers, also to the Exhibitors and the many others who have worked with such energy to make the Symposium not merely, I trust, a success, but one from which will spring benefits, both scientific and practical, of the highest order.

I wish to add one word with regard to the most valuable historical collection submitted by the Education Department. I refer to that from the Science Museum, South Kensington. I also take this opportunity of offering our heartiest congratulations to Sir Francis Ogilvie, the Director of that Museum, upon his recent well-deserved Knighthood.

We have, too, with us this evening many important Members and visitors who have done much for the microscope. Amongst them is my friend Dr. J. E. Stead, who has greatly helped metallography. I am sure you will all be glad to learn that he is in May next to become President of that important body, the *Iron and Steel Institute*. We wish him health and strength and a most successful term of office.

I am sure I shall be excused for referring to family matters. Of course, as family matters are, it is strictly private, but as we are one big family to-night we should like you all to share in our joys. It is not often that after quite a considerable interval of time it is possible to bring together the Founders of a Society. The changes and chances of this mortal life step in and sadly break continuity, but in this special case I am glad to tell you we have present with us this evening, with one unavoidable exception—and, happily, this is not owing to the member in question not being in the land of the living—all the Founders of the Faraday Society. I refer to Mr. Sherard Cowper-Coles, Mr. W. R. Cooper, Prof. F. G. Donnan, Dr. F. M. Perkin, Mr. Alexander Siemens, Mr. James Swinburne

and Mr. F. S. Spiers. It must be a great satisfaction to them to see this magnificent meeting, as one of the fruits of their labours in the past; that is, in seeing the Society they founded, aided by the sister Societies, in the earnest set purpose of assisting our Empire in this important question of improving our resources in optical matters. All honour to the men mentioned, and I am sure that I shall be voicing your feelings in offering them our heartiest congratulations.

Whilst this is a meeting of the "Micro-Intellectuals," may I now descend to earth and remind you that our full programme has its drawbacks. We have the time limit to consider, and I beg that this be borne in mind. If I have occasionally to use the closure it will not be because the words being uttered are not considered words of wisdom, but that the evening is not long enough. I will now try to set the example by making my own remarks as brief as possible.

Sir Robert Hadfield then presented the following "Introductory Address," to the salient features of which he briefly drew attention.

INTRODUCTORY ADDRESS

By SIR ROBERT HADFIELD, Bart., D.Sc., D.Met., F.R.S.,

President of the Faraday Society.

SECTION I.—INTRODUCTION.

As the result of some suggestions I made several months ago to the Council of the Faraday Society, it was arranged to hold this present Symposium on "The Microscope and its Applications." The Royal Microscopical Society (Mr. J. W. Barnard, President); the Optical Society (Professor F. J. Cheshire, President); and the Photomicro graphic Society (Mr. F. Martin Duncan, President) all most cordially approved and agreed to co-operate with us. In view of the fact that the objects of the Faraday Society, as set forth in its Constitution, are not only to promote the study of Electrochemistry, Electrometallurgy, Physical Chemistry and Kindred Subjects, but also Metallography this Symposium is specially appropriate. It is only, or at any rate chiefly, the last named Branch of Research—Metallography—my own remarks are meant to cover, that is, I do not pretend in this Address to deal with the Work of the Microscope as employed by the Geologist, the Zoologist, the Biologist, and other Branches.

During the preparation of this Address I found the interesting frontispiece of the Book by George Adams, "ESSAYS ON THE MICROSCOPE." This was published July 1st, 1787, and contains a Practical Description of the Most Improved Microscopes, revised by Frederick Kanmacher, F.L.S., 1798. I thought this illustration particularly appropriate to form the frontispiece to this present Address of mine. The quaint wording at the foot of the Engraving

"Truth discovering to Time, Science instructing her Children in the Improvements on the Microscope,"

well describes the object of our present Symposium.

As regards the modern application of the Microscope including that to Metallography, below is a portion of the preface to Monsieur Félix Robin's Work "Treatise on Metallography," contributed by Professor F. Osmond, who did so much for Metallurgy, and from

whose work we are to-day greatly benefiting. Robin has, alas, himself passed away during the Great War, gloriously devoting his life on the Field of Battle on behalf of his Country. I make no apologies for referring to this tribute to the Metallographist and for quoting in full the wise words of Osmond. These are well worthy of consideration to-day, and the reasons given by him will, I trust, cheer many an author and many a worker in the fields of research.

Osmond said: "To write a treatise on a branch of Science in process of active development is an arduous task, especially when the author is not a professor and the book not the natural synthesis of the course. It is also a thankless task, for the work of to-morrow will amplify and correct that of to-day. In a few years' time, too, the old edifice must be rebuilt because the new generation no longer deems it sufficiently comfortable in its old form. We ought, therefore, to be indebted to those who have the courage—which I have always lacked—to collect and collate scattered material. Those who continue the work are thereby saved the trouble of lengthy visits to libraries and the search for documents of sometimes questionable value disseminated in the periodicals of all civilised countries. But M. Robin's book is not a mere compilation. The author, whose numerous papers have evoked the attention of, and have been the subject of numerous awards by, the British Iron and Steel Institute and others, has been working whole-heartedly for some years past in the direction of extending our knowledge of Metallography and its kindred Sciences. His contributions to this Science have been most useful, and he is thus in a position to enrich the present treatise by his personal experience and minute observations, to the great benefit of those who will follow him."

> " *La science est un pays plein de terres désertes ;*
> " *Tous les jours nos auteurs y font des découvertes.*
> " *Mais ce champ ne se peut tellement moissonner,*
> " *Que les derniers venus n'y trouvent à glaner.*"

WORK OF THE VARIOUS SOCIETIES TAKING PART IN THIS SYMPOSIUM.

The Faraday Society.—Turning to the work of each of the Societies taking part in this Symposium, I deal with that of the Faraday Society in a separate paper presented to this Symposium, entitled "The Work of the Faraday Society and a brief Reference to Michael Faraday." I will therefore not add anything further here. (*See Appendix II, p. 254*).

Royal Microscopical Society.—The Royal Microscopical Society was established in 1839. The late Dr. H. C. Sorby, F.R.S., of Sheffield, the Founder of Modern Metallography and of whom a portrait is given in Fig. 1, was President of this Society in 1876 and 1877. The famous Microscopist, Dr. W. Dallinger, F.R.S., of whom a portrait is given in Fig. 2, and who lived in Sheffield for a number of years, was also President, in the years 1884-7.

Amongst other Past Presidents of this important Society have been Sir Richard Owen, 1840; Edwin Lankester, 1858; John Thomas Quekett, 1860; Lord Avebury, 1907; Sir Edwin Ray Lankester, 1909; Prof. H. G. Plimmer, 1911; and to-day Mr. J. E. Barnard.

It was in November, 1866, that Mr. Secretary Walpole notified the President that Her Majesty had been graciously pleased "to command that the Society shall be styled the Royal Microscopical Society."

Singular to say, notwithstanding his early work in 1857-1863, Dr. Sorby, even in his own Presidential Addresses in 1876-1877 to the Royal Microscopical Society, made no reference to the use of the Microscope for Metallurgical Research. Apparently, he himself had not then applied his method of study, but the germ was there waiting to be developed. Professor W. G. Fearnsides has pointed out in his interesting account of Sorby's lifework in the first Sorby Lecture delivered before the Sheffield Society of Engineers and Metallurgists in 1914, "On some Structural Analogies between Igneous Rocks and Metals," that it was in the year 1885, by the use of Lenses of high resolving power and comparatively large magnification, Sorby first saw the true composite nature of the "pearly constituent" of Steel as an aggregate of parallel plates. This discovery was the earliest recognition of the formation of crystals from a solid solution, and may be regarded as the crowning achievement of his microscopical research. He announced this discovery to the Iron and Steel Institute in 1886, and in 1887 presented to the same Institution his historical Paper on "The Microscopical Structure of Iron and Steel," which gave a full account of his methods and the results he had obtained.

A well-known American writer, in a biographical sketch of Sorby published in "The Metallographist" for April, 1900, stated: "Whatever has been accomplished since in Microscopic Metallography has been done by following in his footsteps. To Dr. Sorby, and to him alone, is due the pioneer's honour."

I had at first intended to include in this Address my remarks regarding the great work performed by Sorby for "The Metallographist." In view, however, of the importance of the subject, and that some of our younger members may not be aware of the facts, I have thought it best to embody and present these in a separate short communication entitled "The Great Work of Sorby."

Optical Society.—As regards the Optical Society, which now has its Headquarters at the Imperial College of Science and Technology at South Kensington, this was founded in 1899, its first President being Mr. W. H. E. Thornthwaite, F.R.A.S. Subsequent Presidents have been Dr. R. M. Walmsley, Professor Silvanus Thompson, Dr. W. Rosenhain, Sir Richard Glazebrook, Sir David Gill, and to-day Professor Cheshire, C.B.E., who did such excellent work in the War.

Photomicrographic Society.—The Photomicrographic Society was founded in 1911 by a small band of Microscopists and Photographers, including Fellows of both the Royal Microscopical and Photographic Societies, having for its objects, to quote from its Rules, "the study

of Photomicrography and the discussion and demonstration of any subjects of interest concerning it." From the first the Society was a success, as evidenced by continual increase of Membership, and this is perhaps due to the wide field in Research, Engineering, Natural History, Industrial and other Processes, in which the Microscope is essential. This is also shown in the diverse nature of the subjects in which individual members are specially interested, but who alike have to record their observations by Photography. Others again are interested purely in the optical equipment of the Microscope and the special problems presented to the photomicrographic worker. The essential importance of correct microscopic technique, especially proper illumination to obtain a correct image, has always been recognised, and great attention has been paid to the mechanical side, as shown by apparatus designed and built by several members and exhibited from time to time.

Mr. F. Martin Duncan now occupies the Presidential Chair, and Mr. J. E. Barnard was President in 1915-16. A Medal is awarded annually, for the best results in Photomicrography from both the microscopical and photographic point of view.

The Society meets twice monthly at King's College, and has papers on the many subjects in which the use of the Microscope is essential, together with other meetings of a less formal character for discussion, exhibition of photomicrographs, and apparatus connected with Photomicrography.

For the foregoing information I am indebted to the Honorary Secretary and Treasurer, Mr. J. G. Bradbury, who has done so much good work on behalf of this useful Society.

British Science Guild.—The Committee on the Microscope appointed by this Body, with its Chairman, Dr. Walmsley, have also been kind enough to give much useful help with regard to our Symposium.

It will be seen therefore that the Faraday Society has been successful in enlisting the co-operation and aid of the various special Societies who are also immediately interested in improving Research Work in Microscopy.

OBJECTS OF THE SYMPOSIUM.—The objects of the Symposium are :—

(*a*) Improvement in the technique of the Microscope itself, including its manufacture.

(*b*) Improvement in Lenses including Eye-pieces and Objectives of High Power.

(*c*) Improved application of the Microscope for Research in Ferrous and Non-Ferrous Metallurgy.

With these objects all will be in agreement, and if as a result of this Symposium they are successfully carried out and attained, as I am confident will be the case, our gathering will be not only

noteworthy, but will prove to be of great service to those interested, in our own Country, America, and elsewhere.

PRESENT AND FUTURE WORK.—As regards the particular direction in which Metallurgists should look in the future for further help from the Microscope, may I suggest that one of the objects we ought to have in view should be to obtain increased knowledge from examinations at higher magnifications, that is to say, 5,000, 8,000 and still higher. This may seem ambitious, and I may be wrong as to the value of the knowledge to be so obtained, but I hope not. If there is anything in my belief, a wide vista opens out for further Research Work.

I am contributing along with Mr. T. G. Elliot, F.I.C., a special paper on this important aspect of the subject, entitled "Photomicrographs of Steel and Iron at High Magnification," which I hope will be of interest to our members.

In the past both in England and in America there has been far too much dependence on Germany and Austria for the supply of the best type of Microscope, including constructional details, and high-quality Objectives and Eye-pieces. It is most desirable that in future this situation should be avoided. Forewarned is forearmed, and every possible means must be taken in a fair and open manner to remedy this situation by private enterprise and research, and if necessary by Research Associations aided by the grants allocated by Parliament for such purposes.

To show that it is of the highest importance that this Country should be independent of foreign aid in its supplies of this nature, it may be added that had it not been for the enterprise of just one British Firm with regard to the supply of Optical Glasses at the outbreak of War, we might have been absolutely stranded in the supply of the necessary products, both for apparatus and glassware, so essential in sighting and other instruments of observation used in Modern Warfare.

By these remarks I do not wish to disparage the work of those who until recently have been Enemies, and who in the past wisely equipped themselves by means of Apparatus and Appliances of all kinds as well as by encouraging scientific development. Good work proceeding from any nationality stands fast for all time. Let us, however, now learn the lesson and benefit from the experience gained by us during the War at such bitter cost. It has to be admitted that our Instrument Makers were then necessarily largely employed in other directions and were unable to cater for the requirements of the Microscopist. They could not therefore devote the time so essential for improving not only the mechanical but the optical details of the Microscope, including its Objectives and Eye-pieces. Notwithstanding the many advances made during the War by the Chemist, the Electrician, the Metallurgist, the Engineer, and others, no special claim can be made that much progress has been made by the Microscopist. As far as can be gathered, the methods and appliances now used do not show great advance on those prior to the War. In saying

that it is not meant to indicate that knowledge has not been accumulated and that, for example, we shall in the future be dependent upon foreign supplies as in the past; it is hoped quite the contrary. It is one of the main objects of this Symposium to bring forth and prove that all these requirements can and will be met by the Anglo-Saxon, or at any rate that this will be possible in the immediate future.

It should be added that there stands out very prominently in this connection the important work done on behalf of Glass Technology by Sir Herbert Jackson, K.B.E., to whom we are greatly indebted, and who will give us an important Address this evening.

Reference should also be made to the excellent work carried out on this subject by the National Physical Laboratory, where systematic work on the attack of various refractory bodies by molten glass under carefully standardised conditions has been continued, together with work on the production of crucibles increasingly resistant to such attack. Progress has been made in the application of fused zirconia as a lining for crucibles. In the course of this work special phenomena have been observed in the attack which occurs in some cases at the bottom of the crucible, and in others, at the level of the surface of the glass. These phenomena have been studied by means of experiments on the mode of solution of such substance as wax, naphthaline and plaster-of-paris in ordinary solvents at room temperature where the phenomena could be observed. Most of the features met with in the attack of molten glass on crucibles have been reproduced in such experiments, and a method of preventing the worst features of such attack has been tried and found successful in the model experiments. In addition reference should be made to the valuable work done by the Society of Glass Technology at the University of Sheffield, in which Dr. W. E. S. Turner, the honorary secretary, has played so important a part.

It is certainly most necessary that we should not be behind but abreast of our Foreign competitors in the making of Microscopes and Lenses or their use. One of the prominent objects in holding the Symposium is to arouse still more interest in the advancement of this work.

SECTION II.—HISTORY OF THE MICROSCOPE.

ANCIENT TIMES TO 1600 A.D.

If the Microscope is considered as an Instrument consisting of one Lens only, it is not at all improbable that it was known to the Ancients, and even to the Greeks and Romans. The minuteness of some of the pieces of workmanship of the Ancients would appear to indicate that they must have been executed by the use of Magnifying Glasses. Many passages in the Works of Pliny, Plutarch, Seneca, and others clearly indicate this.

There is reason to believe that the magnifying power of transparent media with convex surfaces was known very early. The convex Lens of rock crystal was found by Layard among the ruins of the Palace of Nimrod. Seneca describes hollow spheres of glass filled with water as being mainly used as magnifiers. It is practically certain that

the perfect gem cutting of the Ancients could not have been attained without the use of magnifiers.

In the Book "Essays on the Microscope" by George Adams, Mathematical Instrument Maker to His Majesty (1787), being "A Practical Description of the Most Improved Microscopes," which was one of the Standard Works at that time, Adams said: "It is generally supposed that Microscopes were invented about the year 1580, a period fruitful in discoveries. The honour of the Invention is claimed by the Italians and the Dutch; the name of the Inventor appears, however, lost."

With regard to the many interesting facts relating to the early History of the Microscope, two valuable contributions have been made by Dr. Charles Singer, M.D., "Notes on the Early History of the Microscope" read before the Royal Society of Medicine in 1914, and "The Dawn of Microscopical Discovery," before the Royal Microscopical Society in 1915.

In giving the following information I have taken the liberty of freely making use of the valuable Researches of Dr. Singer, who points out that there have been three main epochs in the History of Microscopical Discovery. There was the Pioneer Period, extending to about 1660, the Classical Period, covering half-a-century or more from about 1660, and including the work of the great Microscopists, Hooke, Grew, Malpighi, Leeuwenhoek and Swammerdam, and finally the Modern Pèriod, dating from the Optical Discoveries of Newton.

The earliest microscopical observation known is stated by Dr. Singer to be of Seneca (circa A.D. 63) who in his "Quæstiones Naturales" said that "Letters, however small and dim, are comparatively large and distinct when seen through a glass globe filled with water."

The properties of curved reflecting surfaces, and even to some extent of Lenses, were known to the ancients, and to some mediæval writers, such as Roger Bacon. The invention of convex spectacles is attributed to Salvino d'Amarto degli Armata, of Florence, and to Alessandro de Spina, of Pisa, about the year 1300, and these aids to vision were familiar to many throughout the fourteenth, fifteenth and sixteenth centuries. During this period the optical properties of Lenses were investigated by the penetrating genius of Leonardo da Vinci (1452–1519) and by the mathematical skill of Maurolico (1494–1575), while convex spectacles must have been on the nose of many a careful illuminator of manuscripts.

Up to this time Dr. Singer points out there is no single instance on record of these glasses having been used for the investigation of nature and that even the many illuminated manuscripts of the fifteenth and sixteenth centuries, especially of the Flemish school, do not suggest the use of magnifying glasses.

The first illustrated publication, for which there is evidence of the use of a magnifying glass, appeared in the year 1592 at Frankfort, bearing the name of George Hœfnagel (1545–1600). The volume consisted of a series of plates engraved on copper, illustrating common objects of nature, but drawn with exceptional skill and minute accuracy. Some few of these drawings revealed enlarged details which would

have been hardly distinguishable to the unaided eye. These remark able figures are stated to have been the work of Hœfnagel's son, Jacob (1575).

It must be remembered, however, that the occasional use by a naturalist of a simple Lens of low magnifying power could have but little influence on the advance of knowledge. It was not until the Classical Period with the invention of Lenses of very short focus that the simple Microscope became a valuable means of Research. In the Pioneer Period it was rather the discovery that Lenses could be combined into the Telescope and the Microscope that gave the first stimulus to investigation. These compound instruments were invented about the year 1610.

1600 to 1700 A.D.

The Dutchman Zacharias, miscalled Jansen, and his son made Microscopes before the year 1619. It was he who, whilst still a lad, had worked with his father, who was a spectacle maker, and appears to have discovered accidentally the principle of a Telescope by placing two Lenses together in a tube. The invention of the Microscope followed about that time, though the exact date is unknown. In the year 1619, Cornelius Drebbel, of Alkomar, brought a Microscope which was made by the Jansens with him into England and showed it to William Boreel, who was Dutch Ambassador to France, and eventually to England. It is, however, added that Drebbel's instrument was not strictly what is now meant by the Microscope, but was rather a kind of Microscope–Telescope, somewhat similar in principle to certain apparatus described by Mr. Aepinus in a letter to the Academy of Sciences, St. Petersburg. This was formed of a copper tube six feet in length and one inch in diameter. On the other hand, Dr. C. Singer, in his interesting Paper on "The Historical Aspect of the Microscope," does not think this was the case.

A portrait of Jansen is given in Fig. 3. A photograph is also given of Hans Lipperhey (Fig. 4), who is described as the inventor of the second Microscope, Jansen being referred to as the inventor of the first one, that is of the special type described probably in the beginning of the Seventeenth Century.

Dr. Hooke, the author of the famous "Micrographia" in 1665, described means of utilising small drops or globules of glass in a Microscope, and said that by means of this he had been able to distinguish the particles of bodies not only a million times smaller than the visible points, but even to make these visible whereof millions of millions would hardly make up the bulk of the smallest visible grain of sand; so prodigiously do these exceedingly small globules enlarge our prospect into the more hidden recesses of Nature. Di Torre of Naples also largely made use of these globules for his well-known investigations.

As regards Hooke's Book referred to, it may be interesting to give a facsimile (Fig. 5) of the title page as it appeared in 1665. Hooke was a Fellow of the Royal Society, and a facsimile of his signature as it appears in the famous "Roll Call of Fellows" is given at the foot of the front page, in Fig. 5.

As an interesting example of the examination done by Hooke in 1664, and simple as this may seem now, I give in Fig. 6 the result of an investigation he carried out on the point of a small needle, which to use his own words, was

made ſo ſharp that the naked Eye is unable to diſtinguiſh any of its Parts. This, notwithſtanding, appeared before his Microſcope as in the Figure at *a a*, where the very Top of the Needle is ſhewn above a Quarter of an Inch broad; not round or flat, but irregular and uneven.

The whole Piece we have here the Picture of, (according to the Scale given with it) is little more than the twentieth Part of an Inch in Length, and appeared to the naked Eye exquiſitely ſmooth and poliſhed; but, as ſeen by the Microſcope, what a Multitude of Holes and Scratches are diſcovered to us? How uneven and rough the Surface! how void of Beauty! and how plain a Proof of the Deficiency and Bunglingneſs of Art, whoſe Productions when moſt laboured, if examined with Organs more acute than thoſe by which they were framed, loſe all that fancied Perfection our Blindneſs made us think they had! Whereas, in the Works of Nature, the farther, the deeper our Diſcoveries reach, the more ſenſible we become of their Beauties and Excellencies.

But to return to the Object now before us; A, B, C, repreſent large Hollows and Roughneſſes, like thoſe eaten into an Iron-Bar by Ruſt and Length of Time. D is ſome ſmall adventitious Body ſticking thereto by Accident.

b. b. b. ſhew the End where this ſmall Piece of Needle was broken off, in order to take the better View of it.

As ſharp as a Needle is a common Phraſe, whereby we intend to expreſs the moſt exquiſite Degree of Sharpneſs; and, indeed, a Needle has the moſt acute Point Art is capable of making, however rude and clumſy it appears when thus examined. But the Microſcope can afford us numberleſs Inſtances, in the Hairs, Briſtles, and Claws of Inſects; and alſo in the Thorns, Hooks, and Hairs of Vegetables, of viſible Points many Thouſands of times ſharper, with a Form and Poliſh that proclaim the Omnipotence of their Maker.

Another investigation was carried out by Hooke on the "edge of a razor," and to quote his words,

Figure repreſents the Edge (about half a Quarter of an Inch long) of a very ſharp Razor well ſet upon a good Hone, and ſo placed between the Object-Glaſs and the Light, that there appeared a Reflection from the very Edge, which is ſhewn by the white Line *a*, *b*, *c*, *d*, *e*, *f*.

When we ſpeak of any thing as extremely keen, we uſually compare it to the Edge of a Razor; but we find, when examined thus, how far from Sharpneſs even a Razor's Edge appears: That it ſeems a rough Surface, of an unequal Breadth from ſide to ſide, but ſcarce any where narrower than the Back of a pretty thick Knife: That it is neither ſmooth, even, nor regular; for it is ſomewhat ſharper than elſewhere at *d*, indented about *b*, broader and thicker about *c*, unequal and rugged about *e*, and moſt even between *a*, *b*, and *e*, *f*, though very far in any Place from being really ſtraight.

The Side immediately below the Edge, and what the naked Eye accounts a Part of it, *g*, *h*, *y*, *k*, had nothing of that Poliſh one would imagine Bodies ſo ſmooth as a Hone and Oil ſhould give it; but was full of innumerable Scratches croſſing one another, with Lines here and there, more rugged and deep than the reſt, ſuch as *g*, *h*, *y*, *k*, *o*, occaſioned probably by ſome ſmall Duſt falling on the Hone, or ſome more flinty Part of the Hone itſelf.

The other Part of the Razor *L L*, which had been poliſhed on a Grind-ſtone, appeared like a plowed Field, full of Ridges and Furrows.

The irregular dark Spot *m*, *n*, ſeemed to be a little Speck of Ruſt; corroſive Juices generally working in ſuch a manner.

This Examination proves, how rough and unſeemly (had we microſcopic Eyes) thoſe Things would appear, which now the Dulneſs of our Sight makes us think extremely neat and curious: And, indeed, it ſeems impoſſible by Art to give a perfect Smoothneſs to any hard and brittle Body; for *Putty*, or any other ſoft Powder, employed to poliſh ſuch Body, muſt neceſſarily conſiſt of little hard rough Particles, each whereof cutting its Way, muſt conſequently leave ſome kind of Furrow behind it. In ſhort, this Edge of a Razor, had it been really as the Microſcope ſhews it, would ſcarce have ſerved to chop Wood, inſtead of ſhaving a Man's Beard.

In the Bibliography accompanying the present Address will be found reference to some of the writings of other early workers with the Microscope. For example, Antony van Leeuwenhoek, born at Delft in 1632, constructed the first practical microscope and established the art of properly grinding and polishing the Lenses.

Leeuwenhoek was offered, and accepted, the post of Chamberlain of the Sheriff of the town of Delft, worth £26 annually, and held this for 39 years. In February, 1680, he was made a Fellow of the Royal Society. Although he never came to London, the Diploma of Fellowship was sent to him in a silver box, having the Arms of the Society graven on it. An interesting account of his life is given by the President of the Royal Microscopical Society, Professor H. G. Plimmer, F.R.S., in his Presidential Address in 1913.

Leeuwenhoek did wonderful work with his simple or singular Microscope. The largest magnification he obtained was about 160 in one of his Microscopes: his twenty-six other Microscopes varied from 40 to 133 magnifications. With this simple instrument, as Professor Plimmer points out in his address, Leeuwenhoek discovered a new world, in fact new worlds, for us. He saw for the first time Infusoria, Rotifers, and Bacteria. It is interesting to note in this connection that Charles Darwin took no compound Microscope, but only a simple one, with him on his famous "Beagle" Voyage.

So important was Leeuwenhoek's work that I give a portrait of him (Fig. 8).

In the paper "On the Construction of the Compound Achromatic Microscope" by Charles Brooke, M.A., F.R.S., read before the Royal Institution of Great Britain, March 10th, 1854, he states that the first compound Microscopes on record, such as that of P. Bonnani, about 1697, which was placed horizontally, and that of J. Marshall in the beginning of the eighteenth century, which was vertical, were furnished with central condensers. In later years the development of the illuminating apparatus has by no means kept pace with that of the ocular portion of the Microscope, though scarcely of less importance in attaining the highest perfection in the vision of microscopic objects.

On the authority of Adams, the first three compound Microscopes were said to be those of Hooke, Eustachio Divinis and Philip Bonnani. An account of Divinis' Compound Microscope was read before the Royal Society in 1668 (Philosophical Transactions No. 42).

It must be borne in mind, too, that the progress made in the science of Optics was largely aided by the great work of Sir Isaac Newton, Delavel and Herschel.

1700 TO 1800 A.D.

It is stated by Roberts-Austen also in his "Metallurgy" that the Microscope was first applied to the Examination of Iron and the first records go back to 1722 when Réaumur described the structure of Chilled Castings under the Microscope. François in 1832 took

the interesting case of the direct reduction of Iron from its Ores, and followed the successive changes by the aid of the Microscope. Roberts-Austen also claims that: "If to these analytical data observations under the Microscope with a magnification of 300 to 400 diameters be added, it is seen that ordinary Iron is merely a metallic network with a close-grained tissue, with submerged scoriaceous opaline, sometimes sub-crystalline, portions, and with little globules and metallic grains ranged in every direction. Sometimes nests of translucent prismatic and bacillary crystals, with metallic portions adhering, are noticed hidden in the paste. These are the grains of Steel which can be made to disappear by heating."

Roberts-Austen thought that Modern Metallography owed some of its development to the use made of it in the Study of Meteoric Irons, also that it is quite possible, as has often happened in the History of Science, that there are several independent origins.

From 1800 A.D. Onwards.

It is interesting to note that in 1808, Widmanstätten oxidized a heated specimen and took polished sections of meteoric iron, thus originating what is now termed "Metallography."

Sorby in 1856 founded Petrography, employing sliced sections in connection with the Microscope for the study of rocks, the structures of which are in some cases analogous to those of metallic alloys. In the year 1864 he made an examination of meteoric iron, also studying various metallurgical products; while in 1885 he discovered Pearlite When Sorby proposed for the first time to submit a specimen of rail, which had broken and caused an accident, to a microscopic analysis, he was told that it was an insane idea. Sorby's method has since been invaluable for this very purpose—in fact in this Country and in America and elsewhere tens of thousands of photomicrographs have been prepared in connection with the investigation of broken and other rails.

Mr. J. Stuart—himself a veteran of some eighty-four years—of the Clapham Common Optical Works of Messrs. Ross, told me recently that in the 'seventies of the last Century he had repeated visits from Dr. Sorby, who brought various specimens of Steel for examination under the Microscope. Mr. Wenham, Vice-President of the Royal Microscopical Society and the Inventor of the Binocular Microscope, as well as of other microscopical apparatus, was at that time working with Messrs. Ross as their Scientific Adviser. Mr. Wenham was also interested in the study of the structure of steel and had many conversations with the late Dr. Sorby, in fact, constructed for him a high power Binocular which Mr. Stuart believes was the first to be used in connection with the examination of Steel.

Incidentally it may be useful to refer to the fact that the invention of the Oil Immersion Objective was not, as is often imagined, of foreign origin, but was originated by Mr. Wenham in 1870, that is, six or seven

years before Oil Immersion Objectives were constructed at Jena by Professor Abbe. In a Paper read by Mr. Wenham, entitled "Remarks on High-power Definition," at a meeting of the Royal Microscopical Society in June of that year 1870, he says: "Of course there is no optical advantage attendant upon the use of water in immersion lenses. If a medium of the same refractive power as the glass were to be employed the result would be better. Water, having a low refractive index, an adjustment is required for each thickness of cover, and a difference of adjustment is not so marked and sensitive as in the ordinary dry objective; but if a medium of similar refraction to the glass were to be used, no adjustment would be required for any thickness of cover, supposing the test objects to be mounted thereon (which they generally are), for, in fact, we should then view them all with a front of the same thickness—considering the cover, the front lens and the interposing medium as one."

In addition to reading this Paper, Mr. Wenham exhibited at the same Meeting an Oil Immersion Lens using Cedar Oil and an illuminated object showing great brilliancy. It appears, however, he did not at the time realise that his Oil Immersion could have yielded the great numerical aperture which it afterwards gave in the hands of Professor Abbe.

Another interesting point is the fact that Andrew Ross, the founder of the firm of Messrs. Ross, discovered the system of the Collar Adjustment for Water Immersion Lenses and that Mr. Wenham was the Discoverer of the Oil Immersion which required no Collar Correction.

To show how little was thought of the Microscope as a scientific instrument in connection with the study of Iron and Steel, reference may be made to a Book which I have often found useful, namely, Ferdinand Kohn's "Iron and Steel Manufacture," published about 1868 and based upon a series of valuable articles on "The Manufacture of Iron and Steel," which appeared in "Engineering." In this book Kohn says, in the chapter devoted to "Steel under the Microscope," "An experienced steelmaker can estimate very closely the ferrous quality, chemical composition, tensile and compressive strength of any sample of steel, and even the mode of treatment which it has undergone, by looking at its fracture under the Microscope."

It appears, however, this only meant a small hand Microscope. The following are the words: "A Pocket Microscope of this kind ought to be the companion of every man interested in Steel or Steel Manufacture. Lenses of the usual kind, even if piled up in sets of three or four, are entirely insufficient. The Lens must be of a very small focus, and properly achromatic. A little practice is sufficient to enable the user to "see" through this Lens; but it is, of course, not quite so easy to learn the meaning of what is seen, and to estimate from the appearance the quality of the steel inspected."

Special reference was made to some investigations then being carried out (1868) by Mr. Schott, the Manager of Count Stolberg's Foundry at Islenburg, upon the appearance of liquid and solidifying Cast Iron under the Microscope. Mr. Schott contended that each

crystal of iron is a double pyramid upon a flat square base, and that the ratio of height to base of the pyramid is proportional to the carbon content. In Cast Irons and hard Steel the crystals approach the cubical form, whilst in Wrought Iron the pyramids are almost flattened down into leaves. In addition the quality of a steel is shown by the arrangement of the crystals. The highest quality of steel has its crystals in parallel positions with their axes in the direction of the pressure exerted on them in working. An examination of the fracture of a good steel in reflected light shows a series of parallel streaks on the surface, whereas in a bad steel several systems of parallel lines can be seen.

The presence of segregated material and size of the grain can also be seen under the Microscope. The absence of the former and the fineness of the latter indicate good material.

The qualities of parallelism of the material and fine grain seem to be due to different causes. The former seems to be caused by the action of heat, and repeated melting is the great panacea in this respect, whilst the latter is brought about largely by working the material; on the other hand working the material seems to prove that parallelism and high temperature bring about the coarsening of grain.

Singular to say, Kohn does not make a single reference to the work of Sorby, which was evidently then only known by few people.

Dr. Dallinger, F.R.S., who resided many years in Sheffield, gave in the Journal of the Royal Microscopical Society, Vol. 17, 1877, page 224, a "Note on the Ultimate Limit of Vision" as applied to modern Microscopical Lenses. He reasoned that mathematicians of the first order, notably Helmholtz, had concluded that the limit of vision had been reached and that the Optician could practically give no further aid. Dr. Dallinger considered that the limit marked out was about the one-hundred-and-eighty-thousandth of an inch, and added that he did not consider the limit of visibility had been reached.

Dr. Sorby in a Paper on the "Limit of the Powers of the Microscope" to the same Society in 1875 referred to an experiment of Dr. Royston-Pigott which showed that the smallest visual angle he could ever distinctly appreciate was a hole $1\frac{1}{4}$ in. in diameter at a distance of 1,000 yards, which corresponds to about 6 seconds of arc. This visual arc in a Microscope magnifying 1,000 linear would correspond to about three-millionths of an inch.

Tchernoff took up the study of crystallization of Steel, his work being brought before this Country by the late Sir William Anderson. In 1878 Wedding studied Steel by the aid of the Microscope. The work of these investigators caused rapid increase of interest in this subject.

Dr. Martens of Berlin rendered further valuable services, in fact was one of the first to introduce the practical study of Iron and Steel by Metallography. Martens' work commenced about 1878, when he published notes on the Microstructure of Steel.

In 1880 the use of the Microscope was introduced at Le Creusot Works, and important investigations by Professors F. Osmond and J. Werth were started, and from that date were carried out on the lines first indicated by Dr. Sorby.

In his Book on "How to Work with the Microscope," 1880 edition, Dr. Lionel S. Beale, F.R.S., a former President of the Microscopical Society, gave an interesting statement as to the methods of preparing specimens when examining the Microstructure of Iron and Steel.

Roberts-Austen in his book already quoted does just credit to the important work carried out in this Country by Professor J. O. Arnold, F.R.S., who had the great advantage of being in touch and collaborating with the late Dr. H. C. Sorby—in fact the mantle of Sorby descended upon him. Arnold commenced his work about 1890, and the World is under a debt of gratitude for the important results obtained by his valuable labours in this field of research.

Professor Arnold tells me that his first association with Sorby was about 1885 at the Natural Science Section of the Literary and Philosophical Society in Sheffield, where I also met him. When Arnold was appointed to the Chair of Metallurgy in the University of Sheffield in 1889 he persuaded Sorby to resume his micrographic work on Steel in conjunction with his (Arnold's) work on Chemical Analysis, Recalescence and Mechanical Testing, feeling sure that micro work was a vital factor, necessary to render more complete our knowledge of steel. However, Sorby stated he had so much on hand, and his eyesight was failing, that he was not able to take up the work again, but how glad he was to find that his pioneer work was considered to be helpful to Metallurgy. Sorby lent Arnold all his pioneer sections during his lifetime and in his Will left them to the Metallurgical Department of the University of Sheffield. Sorby also gave Arnold his various data and, on several occasions, went through his different sections, which, singular to say, were afterwards destined to be Arnold's for eleven years. Through the kindness of Professor Ripper these specimens are exhibited this evening.

It may be added that Sorby discovered at least five constituents of Steel, Stead three, and the Sheffield University—largely the work of Arnold himself—was responsible for many of the others now known to the World. It was also Arnold who determined the quantitative composition of Sorby's Pearlite and Hardenite.

Dr. J. E. Stead, F.R.S., also at an early date saw the great importance of this branch of investigation, and by his lucid papers and research work has greatly aided the progress of Metallography.

Osmond's unrivalled research work further established modern Metallography in 1895. He discovered successively the constituents of Quenched Steel and accurately determined the critical points of Iron. Moreover he had, along with Werth, previously described the cellular structure of metal. As Sauveur says, if Sorby was the pioneer of Metallography and Tchernoff its father, Osmond has been its torch-bearer.

The work of the Nomenclature Committee on Metallography is useful to those interested in this subject, and will be found in Vol. I

of the Iron and Steel Institute Journal, 1902, comprising some twenty-three pages in its Glossary of Terms.

In addition to the main Societies, who have assisted in developing Microscopy, have been the following: The Sorby Scientific Society, comprising The Sheffield Microscopical Society, and The Sheffield Naturalist's Club, which were amalgamated on January 1st, 1918; the Quekett Microscopical Club; the Dublin Microscopical Club, and the Photomicrographic Society.

Special reference may be made to the excellent work of the Quekett Club, which is probably the most active Microscopical Club in any Country. Its Headquarters are in London, and Meetings are held from time to time. The present occupant of the Presidential Chair is Dr. A. B. Rendle, M.A., F.R.S.

SECTION III.—MODERN WORK ON MICROSCOPES, OBJECTIVES AND EYE-PIECES.

Mr. Conrad Beck, F.R.M.S., many years ago did valuable work on behalf of Microscopy in his Cantor Lectures before the Royal Society of Arts, 1907, on "The Theory of the Microscope." Previous to these Lectures, Mr. John Maynall, junr., gave two excellent series of Lectures on the same subject, entitled "The History of the Microscope." before the same Society.

An able Address was read by Mr. Joseph E. Barnard, now President of the Royal Microscopical Society, in February, 1919, on "The Limitations of Microscopy." Everyone interested in this subject should read the Address, which is divided into various subjects, dealing with dimensions met with in Microscopy, a discussion on the resolving power and limits of resolution and visibility; also descriptions of the Ultra-Microscope and of experiment sillustrating its use, together with a discussion of the advantages of ultra-violet light in ordinary Microscopy; and finally suggestions as to future lines of Research.

As this paper points out, the limit of resolution may be said to have been reached when it is not possible to distinguish the details of the specimen under examination. The limit of visibility is, however, lower than this, for, although no detail can be seen, the specimen can be made visible as a spot in the field of view.

The question of Resolution is touched upon, from which it appears that under the most favourable circumstances, the practical limit is reached when objects in a row are about ·20 micron (1/50,000 cm.) apart. If the body is less than this size under the best microscopic conditions now available no detail can be distinguished.

The Ultra-Microscope shows the presence of much smaller dimensions than those mentioned above, that is, as bright specks on a dark background, but it shows none of the internal features, and no matter what the shape or nature of the object under view, it always appears circular. The smallest particle observable, that is, in the Ultra-Microscope, is that of colloidal gold, about 5 micromillimeters (1/2,000,000 cm.) in diameter. Thus the Ultra-Microscope can distinguish particles about forty times smaller than those which can be resolved under the ordinary Microscope.

Mr. Barnard showed in his Address that whilst the resolving power of a given instrument depends upon its design, it also depends upon the wave-length of the light used to illuminate the object under examination. Thus, if the object is illuminated with ultra-violet rays greater resolution still can be obtained, but, of course, the results are not directly visible and must be recorded photographically.

In a paper recently read before the Royal Microscopical Society by Colonel J. Clibborn, C.I.E., B.A., on " A Standard Microscope," it was stated by Mr. Conrad Beck that the Manufacturers of Microscopes worked under great difficulty during the War. It was not until after the 11th November, 1918, that any Microscopes were allowed to be made, all the Factories being fully engaged on other Optical Instruments. It is interesting to note, however, that these Firms are now spending large sums in manufacturing tools for the production of Microscopes, many of them to be made under the Specifications brought forward by the Committee on Microscopes. appointed by the British Science Guild.

At the recent British Scientific Products Exhibition an excellent set of Exhibits was shown by the British Optical Instrument Manufacturers' Society, Ltd. Some dozen or more of the principal firms exhibited Optical Instruments and Glasses.

As pointed out in the valuable Catalogue of that Exhibition, the Optical Instrument-making Industry originated in most of its Branches in Great Britain. Newton, Young, Faraday, Clerk Maxwell and Rayleigh were the pioneers of Optics. The Achromatic Telescope was invented by Dolland, and the modern form of Achromatic Microscope by Lister. Let us therefore show that we are trying to be worthy successors of these great men.

The Optical Association has published an illustrated booklet on Scientific Instruments, which includes, with a brief description, the name of every known instrument both current and obsolete, together with a key to the British Makers. The Trade has set up a powerful Research Association and has participated in the inauguration of a Scheme of Education in Optical Engineering which is being developed by the Imperial College of Science and Technology at South Kensington. It may be mentioned that the Governing Body of the Imperial College of Science and Technology recognises the importance of Technical Optics in their relation to the needs of the Nation by providing in the Estimates of their new Scheme of Development the sum of £50,000 for expenditure on Land, Buildings and Equipment, and the sum of £4,000 annually for maintenance and carrying on the work.

Messrs. Chance Brothers commenced the manufacture of Optical Glasses in England in 1848. During the recent War they increased their output some twenty-fold. They make something like seventy different types of Optical Glasses together with a number of new types which have been recently introduced. They have rendered great service to our Empire.

Professor J. C. McLennan, F.R.S., of the University of Toronto, who was in England during the War, informed me that he had examined the Fluorite from South Africa and found it to be excellent in quality.

If this Fluorite can be used in the manufacture of Glass suitable for High Power Objectives, then the South African source of supply should be borne in mind. It is also stated that Fluorite exists in Canada, and our Honorary Treasurer, Dr. Robert Mond, is investigating this matter,

The King recently visited the Leicester Works of Messrs. Taylor and Hobson, the famous Lens experts. He there saw the instruments by which vital errors of a few millionths of an inch are avoided, and had explained to him the principles of the use in this connection of light interference, which was first studied by Sir Isaac Newton in Soap Bubbles. This Firm also make the "Aviar" Lens, which through repeated calculations and readjustments of formulæ enabled the British Photographing Aeroplanes to beat the "Archies."

In a recent number of the "Scientific American Supplement" (August 30th, 1919), a statement is made that in spite of the traditional superiority of the German Optical Industry, during the War their Lenses proved distinctly inferior to those of French and English make. The English developed superior Lenses during and under the stress of the War.

In a perfect High Power Objective known as Apochromatic, it is desirable this should give :—

(*a*) *Full Resolution.*—The resolution increases with, and is a function of, Numerical Aperture. The number of lines to the inch which an objective will resolve, if perfect, may be calculated from the Numerical Aperture.

(*b*) *Good Definition.*—Which could be magnified by a × 28 eye-piece or its equivalent without breaking down.

(*c*) *A Perfectly Flat Field.*—This is never actually obtained.

(*d*) *Freedom from Chromatic Aberration.*

Achromatic Lenses generally give good definition and their field is often somewhat flatter than in that of the Apochromats. They do not, however, give such good resolution, and are only partially colour corrected. The latter failing makes them much less efficient than the Apochromats for photographic work.

The foreign 2 mm. Objective used in the Hadfield Laboratory is a very good one of its class. Its Numerical Aperture is 1.3, and therefore according to the formula of Professor Abbe, should, if perfect, resolve about 92,000 lines to the inch. I have had photographs taken by it which show 85,000 lines to the inch clearly resolved. Its definition begins to break down with an eye-piece magnification of about 15. For an Apochromat its field is very flat, and it is in this respect chiefly that we found it superior to other Apochromats we examined. Its colour correction is apparently perfect.

It may be added that Messrs. Watsons supplied to the Research Laboratory of my firm a very excellent 2 mm. Objective.

In fact photomicrographs obtained with it seemed to possess almost equal quality to those from the best foreign objectives. Fig. 13 is a photomicrograph of a specimen of Steel taken with the above-mentioned foreign 2 mm. Apochromat, whilst Fig. 12 is a photomicrograph of the same section under exactly similar conditions, taken with the Watson 2 mm. Apochromat. It will be seen that there is very little to choose between the two photographs from the point of view of resolution and flatness of field. There is no doubt that English makers can, when required, produce Objectives at least equal in quality to the best foreign makes.

SECTION IV.—FERROUS METALLOGRAPHY.

Several excellent Works have been published on the important subject of Metallography, including "Physical Metallurgy," by Dr. Walter Rosenhain, F.R.S., which has proved of the highest service. No book, too, on the subject has been of greater use in the past than that by Professor Albert Sauveur, of Harvard University, "The Metallography of Iron and Steel." Great advances have been made since the date of its first publication, and in the second edition, 1916, it remains a standard work of reference and a model for books on a special subject —excellent matter, well printed and illustrated. The chapters are divided into Lessons, some twenty-four in all, commencing with the Study of Pure Metals; Pure Iron and Steel, up to High Carbon Percentages; the Effect of Impurities Upon Steel; Close Studies of Thermal Critical Change Points; the Effect of Annealing, Hardening and Tempering upon both ordinary and Special Alloy Steels, are considered. The Metallography of Cast Iron also receives attention. Various Apparatus for the Metallographic Laboratory, including the study of the Microscope itself, and the Apparatus, Illumination, Sources of Light, Condensers, and Photomicrographic Cameras; a description of the best Methods and Manipulations; also a most excellent nomenclature of the various Microscopic Constituents, including Austenite, Cementite, Martensite, Ferrite, Osmondite, Ferronite, Hardenite, Pearlite, Graphite, Troostite, Sorbite, Manganese Sulphide, and Ferrous Sulphide.

In words which deserve consideration by us all, so I quote them in full, Professor Sauveur in his Introduction and Remarks upon the Industrial Importance of Metallography, points out:

"Invaluable information is given by chemistry without which both the physicist and the metallurgist would be in utter darkness, but this science throws little or no light upon the anatomy of living or inanimate matter. Its very methods, which call for the destruction of the physical structure of matter, show how incapable it is to render assistance in this, our great need.

The parallel drawn here between metals and living matter is not fantastic. It has been aptly made by Osmond, who said rightly that modern science was treating the industrial metal like a living organism, and that we were led to study its anatomy, that is, its physical and chemical constitution; its biology, that is, the influence

exerted on its constitution by the various treatments, thermal and mechanical, to which the metal is lawfully subjected; and its pathology, that is, the action of impurities and defective treatments upon its normal constitution.

Fortunately Metallography does more than reveal the proximate composition of metals. It is a true dissecting method which lays bare their anatomy—that is, the physical grouping of the proximate constituents, their distribution, relative dimensions, etc., all of which necessarily affect the properties. For two pieces of steel, for instance, might have exactly the same proximate composition—that is, might contain, let us say, the same proportion of pearlite and ferrite, and still differ quite a little as to strength, ductility, etc., and that because of a different structural arrangement of the two proximate constituents; in other words, because of unlike anatomy.

It is not to be supposed that the path trodden during the last score of years was at all times smooth and free from obstacles. Indeed, the truth of the proverb that there is no royal road to knowledge was constantly and forcibly impressed on the minds of those engaged in the arduous task of lifting metallography to a higher level.

Its short history resembles the history of the development of all sciences. At the outset a mist so thickly surrounds the goal that only the most courageous and better equipped attempt to pierce it and perchance they may be rewarded by a gleam of light. This gives courage to others, and the new recruits add strength to the besieging party. Then follow the well-known attacking methods of scientific tactics and strategy, and after many defeats, and now and then a victorious battle, the goal is in sight, but only in sight and never to be actually reached, for in our way stands the great universal mystery of nature: what is matter? what is life?

Nevertheless there is reward enough for the scientist in the feeling that he has approached the goal, that he has secured a better point of vantage from which to contemplate it. The game was worth the candle, and if scientific workers must necessarily fail in their efforts to arrive at the true definition of matter, whatever be the field of their labour, they at least learn a great deal concerning the ways of matter, and it is with the ways of matter that the material world is chiefly concerned. Hence the usefulness of scientific investigation, hence the usefulness of metallography."

Among the many workers who have contributed to the progress of Metallography may be mentioned:—Arnold, Benedicks, Belaiew, Brearley, Carpenter, H. Le Chatelier, Campbell, Desch, Edwards, Elliot, Guillet, Gulliver, Giolitti, Hatfield, Honda, Howe, Humfrey, Hudson, Zay Jeffries, Law, Martens, McCance, Osmond, Portevin, Roberts-Austen, Rosenhain, Robin, Sorby, Sauveur, Stead, Thompson, Werth.

In the valuable Pocket Encyclopædia on "Iron and Steel" by Mr. Hugh P. Tiemann, B.S., A.M., with an introduction by Professor H. M. Howe, some thirty pages are devoted to Metallography. The book contains a most excellent summary of the terms used in this Branch of the Science of Metallurgy, treating of the constitution and structure of Metals and Alloys, also their relation to physical properties.

Tiemann says that originally the term Metallography concerned principally the visual examination of the structure of metals, and hence was divided into Microscopic Metallography, or, briefly, Micrometallography, where Microscopes were used to secure high magnifications, and Megascopic, Macroscopic or Macro-Metallography, where the naked eye or very low magnifications were used. The terms Microscopy and Micrography are also used.

With reference to Metallographic Examination, Tiemann considers that the methods employed may be classified into :—

(1) OPTICAL ANALYSIS: Determining the Constituents, structures, forms, appearances, etc., by the eye alone or assisted by suitable magnifying devices.
(2) THERMAL ANALYSIS: A Study of the nature of metals and alloys by means of heating and cooling curves, changes in specific heat, etc.
(3) MAGNETIC ANALYSIS: Determination of changes in nature affecting the magnetic properties.
(4) PHYSICAL ANALYSIS: Determination of the properties by the usual methods of testing.
(5) CHEMICAL ANALYSIS: Both proximate and ultimate; generally in conjunction with one of the other methods.

He defines the Microscope as follows :—

(*a*) A simple Microscope is one which has only one Lens or set of Lenses; a compound Microscope has two such systems of Lenses, one near the object (Objective) and the other near the eye of the observer (Eyepiece).
(*b*) The binocular Microscope consists of two instruments mounted to give a stereoscopic (perspective) view.

As regards the minute nature of matters forming metals and alloys of metals, an interesting statement is made by Mr. Zay Jeffries, D.Sc., Cleveland, U.S.A., who, when speaking of the ageing of the non-ferrous metal known as Duralumin, in his paper on "The Micro-mechanism of the Ageing of Duralumin," says that when it is cooled from 500° C. in a furnace, globules of $CuAl_2$ large enough to be seen easily with a high power Microscope, are formed. In the same sample, however, some globules are so small as to be hardly distinguishable, and others too small to be resolved are suggested by the non-uniformity of the surface appearance of the section. When it is considered that the smallest globule of $CuAl_2$ resolvable with a high power Microscope contains about 2,000,000,000 molecules, it is evident that with rapid cooling sub-microscopic particles of $CuAl_2$ must be present in large numbers; in fact, after quenching, the average size of a particle must be sub-microscopic. The whole phenomenon of ageing must, therefore, involve changes which cannot be studied directly with a Microscope.

The same author has devoted a great amount of time to the study of grain sizes and their measurement in metals. He has contributed several papers to the Faraday and other Societies in this country. Much valuable information is to be found in the work done by Dr. Zay Jeffries.

PREPARATION OF SPECIMENS AND ETCHING.—In the preparation of specimens for micro-examination great skill and ingenuity have been displayed by numerous investigators from the time of Sorby onwards.

When it is considered that a maximum magnification has now been reached of about 8,000, the difficulties to be overcome will be readily recognised. Supposing the surface of one side of a cube, say one twenty-fifth of an inch square, to be under examination, this has meant that the area under observation has been multiplied or magnified to a surface of say 30 ft. square, or about 900 square feet. It will be seen how the slightest scratch or groove, imperfect polishing, bad etching, or other defect will at once interfere with the desired results being obtained.

In this connection I should like also to call attention to an interesting Paper read by Sir G. T. Beilby, F.R.S., before the Royal Society in February, 1914, entitled "Transparence or Translucence of the Surface Film produced in Polishing Metals." Some beautiful Photomicrographs are there shown, photographed by a 3 mm. Oil immersion Lens of 1.4 N.A. The thickness of the films covering the slight Pits on a Copper surface was stated by Sir George to be probably of the order of 10 to 20 micro-millimetres ($\frac{1}{2,500,000}$ to $\frac{1}{1,200,000}$ inch).

Although if it was possible to get raw surfaces free from all grooves, scratches, and other blemishes, some structure would be developed, it must be remembered that not even the finest polishing will display structure, therefore etching must be employed.

The etching accomplishes two things: it removes the amorphous layer, and then attacks the various constituents differently. The products of the etching attack usually differ in appearance more than the original constituents.

For high power the etching must be very light, that is, the time of etching must be short. A 5 per cent. solution of picric acid in alcohol gives the best results. The perfect flatness of the polished surface must be retained, and only the lightest possible etching is given. In low power work the etching is fairly strong in order to obtain contrast between the light and dark portions.

As regards the effect of different kinds of etching, I invite attention to Photomicrographs, Figs. 9, 10 and 11. These are from a Gun Tube Steel containing .42 per cent. Carbon, .74 per cent. Manganese, and representing material as forged, that is without further treatment.

Fig. 9 was etched with 5 per cent. Picric Acid in Alcohol.
Fig. 10 was etched with 5 per cent. Nitric Acid in Alcohol.
Fig. 11 was etched with 5 per cent. Solution Meta-Nitro-Benzol-Sulphonic Acid.

The structure shows grains of Ferrite on a ground mass of Pearlite and the Photomicrographs prove that the Structure developed is independent of the particular etching reagent used. The number of etching reagents might be extended on this work with practically the same results in each case. Most Alloy Steels, for example, Manganese Steels, quenched and tempered. Nickel Chromium and other Steels.

require extraordinary care in the etching or otherwise the structure will vary considerably and be misleading. Some alloys, for example Steel containing high percentage of Nickel, are not attacked by any ordinary etching reagent.

All honour to Sorby, the man who led the way in this branch of Science, and started us, who are to-day benefiting in such a remarkable manner from the knowledge he first originated and obtained in this important and complex branch of Science. All honour, too, to the band of willing workers who have accomplished such great progress, and who have surmounted the many difficulties in their path.

SECTION V.—STANDARD MAGNIFICATIONS FOR PHOTOMICROGRAPHS.

The question of the Standardisation of Magnifications for Photomicrographs of Metals and Alloys has been given a certain amount of discussion both in this Country and in America.

Committee E-4 of the American Society for Testing Materials has, in fact, drawn up tentative "Definitions and Rules governing the Preparation of Micrographs of Metals and Alloys," which include Standard Magnifications for general use, and Ferrous and Non-ferrous Metals. I have brought this matter before the British Engineering Standards Association, who are considering the subject. The Institute of Metals in this Country in its "Notes for Authors" also specify certain Standard Magnifications which it is desired Authors should use.

Whilst not wishing in any way to hamper the Research Worker, there are reasons why it seems strongly advisable that for general purposes Standard Magnifications should be adopted for the Photomicrographs. Very little quantitative data is forthcoming from the micro-examination of metals. Where the grain size can be determined, this is often distinctly useful and worth recording. For the most part, however, the Microscopist is dependent on a trained eye, resulting from prolonged experience in the examination of microstructures to aid him in their interpretation. It would seem reasonable, therefore, that the magnifications used should be standardised and as few as possible, in order that comparisons between the structures of different specimens may be facilitated.

I would therefore like strongly to urge that the various Societies interested in Metallography should join in drawing up rules governing the reproduction of photomicrographs, which should be of certain Standard Magnifications and naturally should be reproduced full size.

Surely there is every reason for having an International Standard; at any rate, Great Britain and America could work together. It might well, indeed, be made a matter for Allied consideration, or one for consideration in connection with the movement for the formation of International Unions in which the Conjoint Board of Scientific Societies is interesting itself.

SECTION VI.—CRYSTALLOGRAPHY.

As crystallography is, if not directly then indirectly, related to the work of the microscope, I have asked my friend, Dr. A. E. H. Tutton, F.R.S., the eminent crystallographist, to communicate suggestions to this Symposium by way of a Paper or to the Discussion from his point of view.

During the recent Meeting at Bournemouth of the British Association, Miss Nina Hosali, B.Sc. of the University of London, exhibited interesting Models of Crystals. This worker has most kindly submitted her collection this evening and I am sure they will be found useful.

As explained by Miss Hosali, the object of these models is to illustrate :—

(*a*) The forms possible to crystals.
(*b*) The different kinds of symmetry possessed by these forms.
(*c*) How the forms are referred to crystallographic axes.

Each model illustrates one of the thirty-two classes of symmetry, and represents several crystal forms correctly orientated with regard to crystallographic axes, the latter being shown by black threads. A model consists in the first place of a glass envelope whose shape is hat of some simple crystal form, and within this envelope two or three other forms are represented by means of coloured silk threads stretched over frameworks of thin copper wire. By this means it is easy to make the forms intersect if necessary, and they are readily distinguished from one another by the use of differently coloured threads.

The symmetry elements of the class represented by any model are shown as follows :—

(*a*) The traces of the Planes of Symmetry on the Glass envelope are shown by steel wires.

(*b*) Axes of Symmetry are shown by white threads.

The set of 24 models exhibited represents 21 out of the 32 classes and over 70 different forms. In many cases different varieties of the forms may be produced by rotating or inverting the models, or by reflecting them in a mirror, and when these modifications are taken account of, the number of the forms shown is brought up to about 140.

It may be interesting to add that there has been recently developed and described by the Research Committee of the American Society of Mechanical Engineers an instrument called the Microcharacter (from the Greek—to engrave or scratch on a small scale). This instrument determines that characteristic of a crystal which is the combination of three of the five fundamental conceptions of hardness, namely, the combined effect of cutting, scratch, and penetration hardness. It can be employed for determining the hardness of the micro-constituents of steel and should be very useful to the Metallographist. This Apparatus should be very useful to the Metallographer, as the

point used is practically sharp under a magnification of no less than 2000 diameters. By this method these combined characteristics can be obtained for any individual crystal, a point of great importance.

SECTION VII.—THE ULTRAMICROSCOPE.

Much study has been given to the Ultramicroscope, which was introduced about the year 1905 by Siedentopf and Zsigmondy.

In an article which appeared in "The Scientific American," October 2nd, 1915, it was stated that the limits of microscopic observation with direct illumination is about $\frac{1}{4,000}$ mm. and with oblique illumination by means of violet rays and with the aid of monobromated naphthalene immersion $\frac{12}{100,000}$ mm. The observation of particles below this may be termed ultramicroscopic. According to Siedentopf, particles may be perceived which have a diameter of about $\frac{4}{1,000,000}$ to $\frac{6}{1,000,000}$ mm. These are magnitudes which approach very closely to molecular dimensions of complicated compounds, in some cases even attain them.

According to O. E. Meyer, the molecule of Hydrogen has a diameter of $\frac{1}{10,000,000}$ mm., while according to Jaeger, the molecule of (*a*) ethyl-alcohol has a diameter of $\frac{5}{10,000,000}$ mm.; (*b*) chloroform has a diameter of $\frac{8}{10,000,000}$ mm. According to Lobry de Bruyn, the molecule of starch has a diameter of $\frac{5}{1,000,000}$ mm. Consequently the molecule of starch must be within the reach of ultramicroscopic perception.

The investigator has therefore before him, subject to increased intensity of light and dark field, the possibility of seeing molecules which seemed beyond reach of human sight, and the hope of following the play of their attractive and repellant forces. The brightness of ultramicroscopic particles begins to decline with the 6th power of the diameter.

If it should prove possible to obtain this deeper insight into the form and structure of matter, a positive service will be done to philosophy permitting of the observation of particles which were formerly far below the limits of ordinary microscopic observation. If the methods which it renders possible can be extended and applied to Metallurgy, then the Metallurgist will doubtless be possessed of still further means to enable him to advance further our knowledge of the structure of metals and their alloys.

SECTION VIII.—CONCLUSION.

I must now bring these remarks to a close. The subject is a fascinating one, and it has been a labour of love to trace the History of the Microscope and its great development into the wonderful Scientific Instrument of to-day, capable of resolving even over 100,000 lines per inch.

SECTION IX.—BIBLIOGRAPHY OF THE CHIEF LITERATURE RELATING TO MICROGRAPHY.

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Date.	Title.	Author.	Publication.	Country.	Description.
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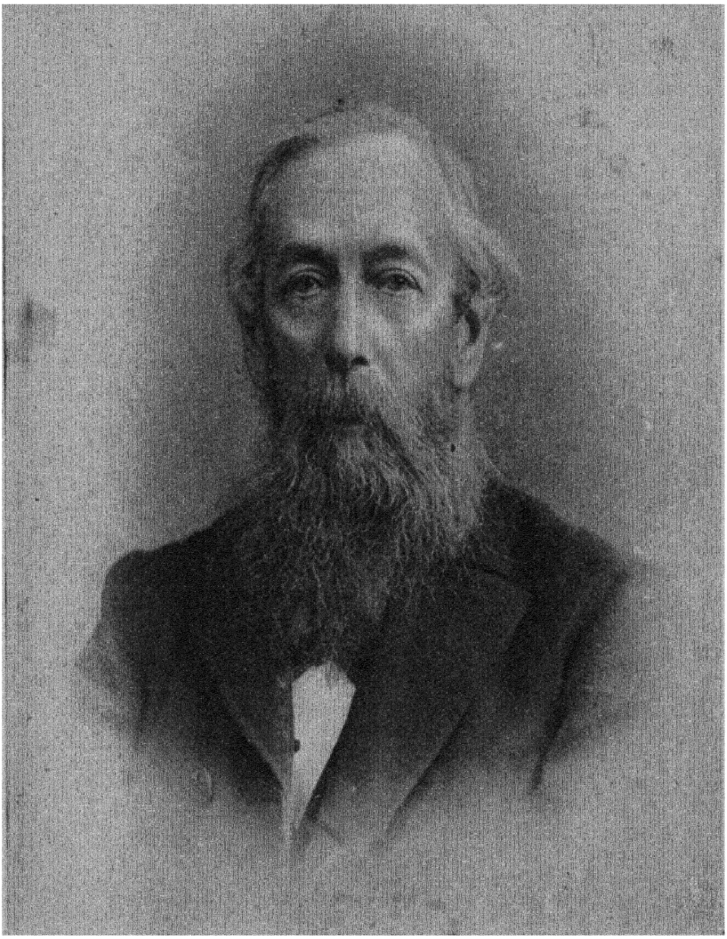
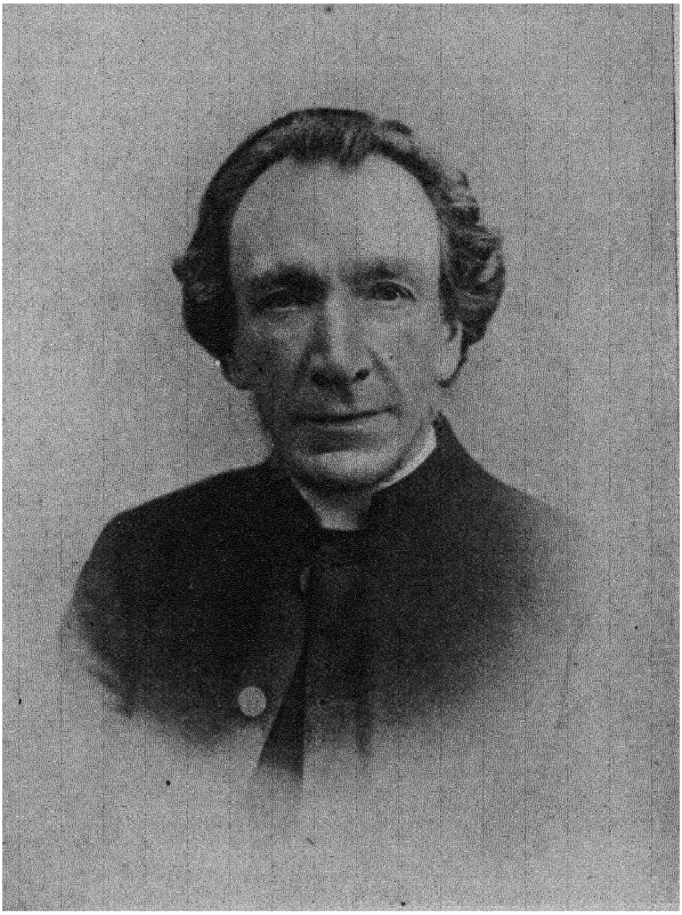


Dr. H. C. SORBY, F.R.S., of Sheffield.

President of the Royal Microscopical Society in 1875-7.

FIGURE 1.



DR. W. H. DALLINGER, F.R.S.

FIGURE 2.

Hadfield 3.

ZACHARIAS IANSEN

ſive Ioannides primus Conſpiciliorum inventor.

FIGURE 3.

FIGURE 4.

Hadfield —'5.

MICROGRAPHIA

OR SOME

Physiological Descriptions

OF

MINUTE BODIES

MADE BY

MAGNIFYING GLASSES.

WITH

OBSERVATIONS and INQUIRIES thereupon.

By *R. HOOKE*, Fellow of the ROYAL SOCIETY.

Non possis oculo quantum contendere Linceus,
Non tamen idcirco contemnas Lippus inungi. Horat. Ep. lib. 1.

LONDON, Printed by *Jo. Martyn*, and *Ja. Allestry*, Printers to the ROYAL SOCIETY, and are to be sold at their Shop at the *Bell* in S. *Paul's* Church-yard. M DC LX V.

Rob: Hooke:

FIGURE 5.—Representing the front page of Hooke's "Micrographia," published in 1665.

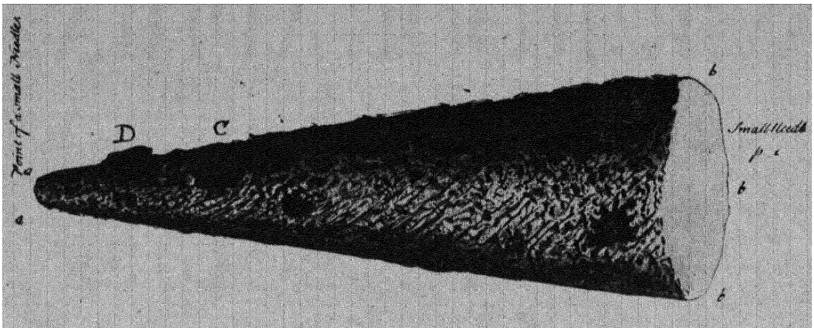
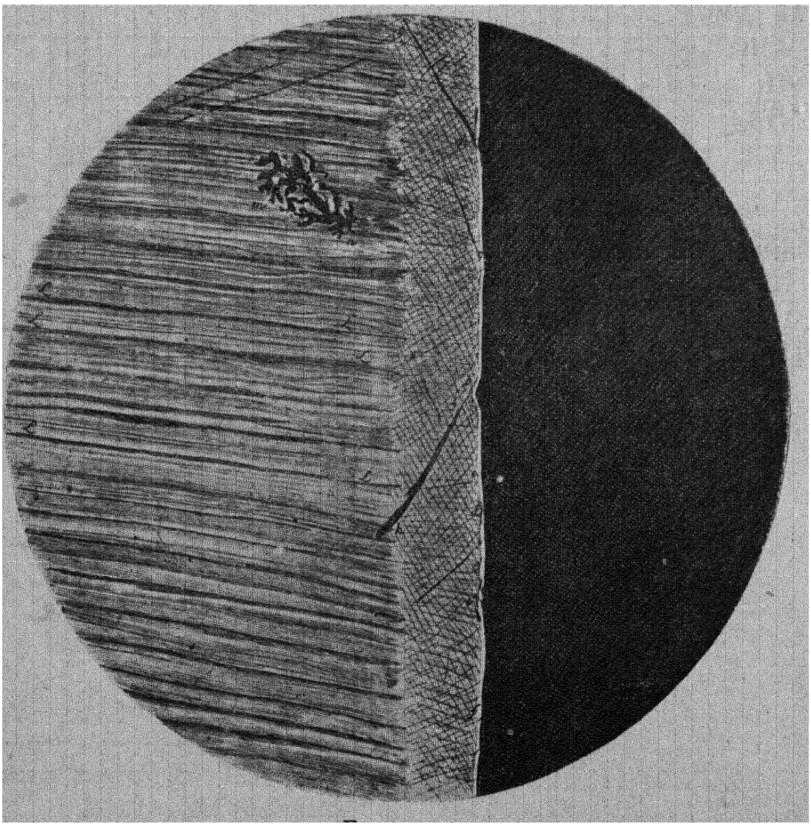


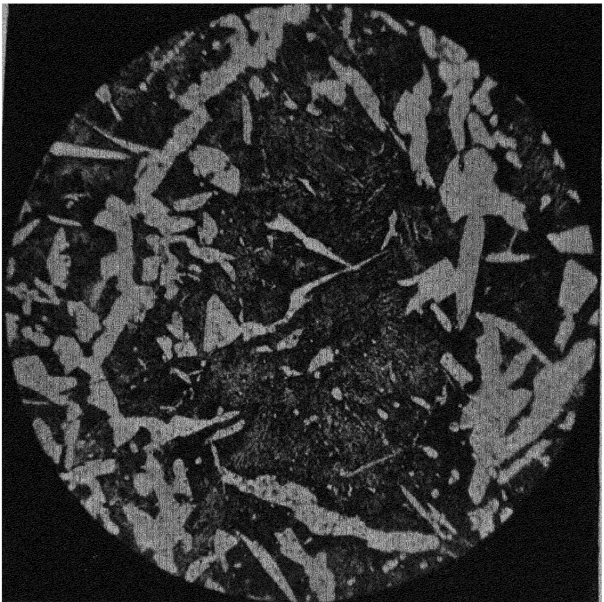
FIGURE 6.
Point of a needle, magnified.
Reproduced from a Drawing made by Hooke in the year 1665.



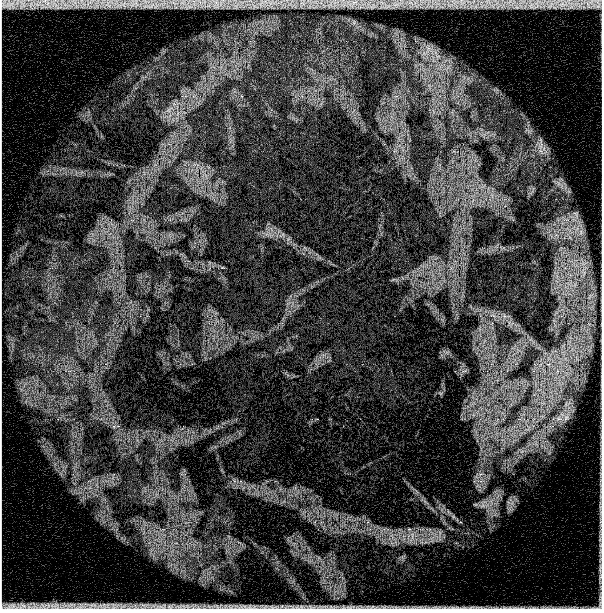
Edge of a razor, magnified.
Reproduced from a Drawing made by Hooke in the year 1665.

These Figures are about three-fifths size of Hooke's enlargement.

FIGURE 8.



Magnification 100.
Etched with 5% Picric Acid in Alcohol.

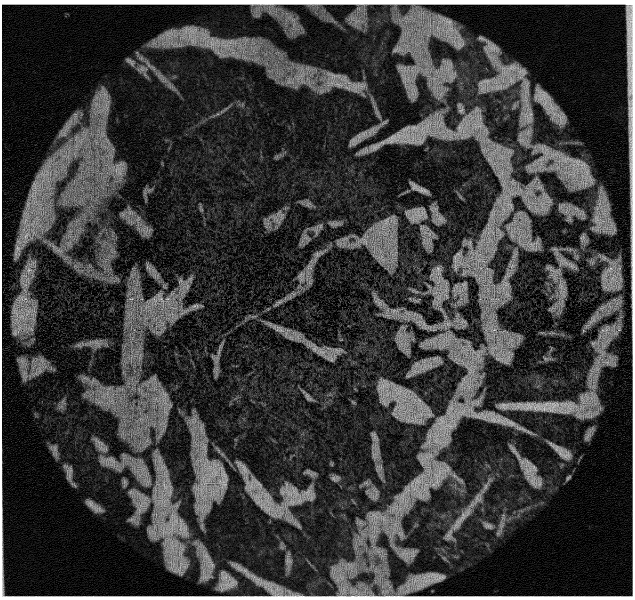


Magnification 100.
Etched with 5% Nitric Acid in Alcohol.

FIGURES 9 AND 10.

Photomicrographs showing that the Structure of a Gun Tube Steel is independent of the etching reagent.

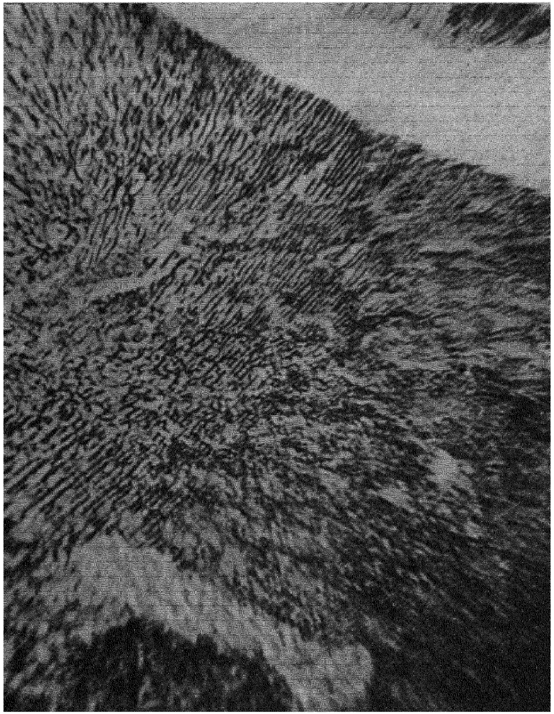
Analysis: C. .42, Mn. .74%.
Treatment: As Forged.
The Structure shows grains of Ferrite on a ground mass of Pearlite.



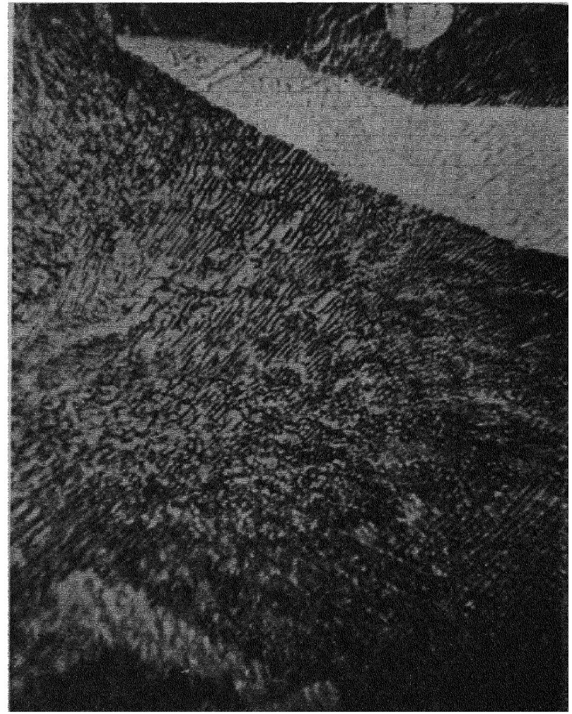
Magnification 100.

Etched with 5% Solution Meta-Nitro-Benzol-Sulphonic Acid.

FIGURE 11.
Photomicrographs showing that the Structure of a Gun Tube Steel is independent of the etching reagent



Watson 2 mm. British-made Apochromat.
Magnification 1,500.
FIGURE 12.



Foreign 2 mm. Apochromat.
Magnification 1,500.
FIGURE 13.

THE PRESENT POSITION AND THE FUTURE OF THE MICROSCOPE—A GENERAL SURVEY.

By J. E. Barnard,

President of the Royal Microscopical Society.

Mr. J. E. Barnard, President of the Royal Microscopical Society, then delivered an address, of which the following is a condensed report, in which he indicated future lines of development in microscope design and in microscopy.

On behalf of the Royal Microscopical Society, I trust I may be allowed to convey to Sir Robert Hadfield the expression of my great appreciation of the efforts he has made, resulting in the holding of this Symposium. The subject is one that is in need of discussion; but, had it not been for Sir Robert's scientific insight and energy, it is unquestionable that the meeting would never have taken place. As the time that is allotted to me is of necessity short, it will be impossible to give anything like a full survey of the subject of microscopy. I shall, therefore, be compelled to limit myself to such points as appear to me to be of interest, although I admit that I am not always selecting the ones of greatest importance.

An examination of the programme of this Symposium might lead to the conclusion that the subject of metallography was the most important branch of microscopical research. In point of fact this is not so. Although the importance of the subject is admitted, yet the amount of attention given to it is not anything like so great as that devoted to biological researches. It is therefore probably quite true that ninety per cent. of the microscopes in use at the present time, whether in this or any other country, are in the hands of those who are working at biological subjects. Even of this class, the science of medicine will absorb the greater portion; and it is therefore unfortunate that the medical side of the subject is treated so lightly—at least, if we may judge from the programme. It is, I am afraid, only in accordance with the accustomed attitude in medical circles for little interest to be taken in pure microscopy, although in diagnostic work the importance of the microscope has never assumed a larger place.

In view of the paucity of contributions on the biological side, I shall, therefore, direct more attention to this than I should otherwise have done, and the few remarks I make will be more particularly in relation to the microscope as used for biological research.

A consideration of the microscope resolves itself of necessity into two parts, the mechanical and the optical. From the mechanical standpoint there are two designs in general use—those referred to as the Continental and the English form of microscope. In the Continental type it has usually been customary to have what is known as the horseshoe foot, mainly, I imagine, because of its ease of construction by mechanical engineering methods; whereas the English design of microscope, which has hitherto been mainly made by hand, is of a more steady type, and the points of support are so distributed as to give more stability to the instrument in any position.

The essential parts of the instruments are a coarse adjustment, to give the body tube a quick motion in the direction of the optic axis, and a fine adjustment, which gives it a much slower motion in the same direction. The tube is adjustable in length, to enable correction to be made for varying thicknesses of cover glass, although a large number of workers appear to regard it as a ready method of obtaining greater or less magnification, with disastrous effects on the resulting image.

There is only one fixed part of a microscope which is used for biological purposes, and that is the stage. But metallographers require that the stage shall also be adjustable in the direction of the optic axis. The body tube itself should be made so that it can be closed to a length of 140 millimetres, including any objective changing device that may be on the nose-piece; and it should be possible to lengthen it to at least 200 millimetres or 250 millimetres if long-tube objectives are used.

All these adjustments are in the direction of the optic axis of the instrument. Two others are usually provided, which are at right angles to this direction—that is, a mechanical stage for actuating the object, and in certain of the best class instruments an arrangement for centering the sub-stage condenser to the axis of the objective. While there are many points which might be raised on the mechanical side, there are only one or two that I have time to mention. The main points about most microscopes appears to be that they are unstable. I have a considerable number in my own possession, but I do not think I have one, even now, which, if I centre an object on the stage with the instrument in a vertical position, still maintains its centration accurately if the instrument is put into the horizontal. The probability is, therefore, that there are few microscopes made at the present time that exactly fulfil the conditions necessary for high-class photomicrographic work, or for observational microscopic work of an exacting order. I trust, however, that an instrument exhibited at this Symposium will embody the necessary improvements to rectify this matter.

Some misapprehension appears to me to exist also as to the relative purpose of the coarse and the fine adjustments. The coarse adjustment should be sufficiently well made, and if the user is sufficiently expert, to enable him to bring into view any object, whether it is being observed with a low or a high power objective. The fine adjustment is then used for accurate focussing and for getting a conception of the object in depth. In biological work, at any rate, this is very rarely the state of affairs as carried out. In using

an oil immersion objective, for instance, a common method is to immerse the objective and then lower it so that it all but touches the top surface of the cover glass. The objective is then raised by means of the fine adjustment until the object comes into view. While this may act fairly well with very thin cover glasses, it is a haphazard method when cover glasses of varying thicknesses are used. It should be realised that when microscope users are sufficiently educated, they will be able to tell how far they are from the actual image by the appearance of the light in the field of view, that is, if the object is illuminated with reasonable accuracy.

Mechanical stages also appear to me to need some consideration. The stages which will on actuation cause no shift of the object other than in the direction intended, or any alteration of focus, are rare. Further, those in which the screws project over the side for a considerable distance with the result that any slight jar or knock causes them to be displaced, and, it may be, actually bent, are objectionable when used under laboratory conditions.

There is, I think, much to be said for the type of stage which has either co-axial milled heads on a vertical axis, or, if inconvenient to make, milled heads which are on separate axes. This method of construction, I think, of necessity results in a much stiffer and more stable stage. There is, in fact, a general lack of stability going through nearly all parts of a microscope. But it is significant that, even so long ago as the beginning of last century, the instrument as then designed had much greater attention paid to this point. The microscope, an illustration of which I show on the screen, is to my mind an embodiment of a principle that should receive attention. So soon as English makers are in a position to consider the production of an instrument of a special type, it is my intention to have one made. In this the general principle is that all the optical parts are carried on a bar which is, in effect, an optical bench, and that this is strutted in such a way as to give stiffness to the instrument as a whole. The only effort that I am aware of that has been made in this direction is in the microscope designed by Dr. Rosenhain, particluarly for metallography, but which is adaptable for ordinary work. This instrument, to my mind, is such an improvement on any other type of stand that I am at a loss to understand why metallographers have not more generally taken it up. It might appear that I am exaggerating the importance of stability in the stand. But it should be realised that any want of centration in the optical parts, or want of alignment in the optic axes of these parts, results in more serious deterioration of the resulting microscopic image than any other single factor. The optical parts of a microscope are the objective, for obtaining the primary magnified image of the object; the ocular, for further enlarging that image and transmitting it to the eye; and the sub-stage condenser, for illuminating the object with a larger or smaller cone of light. The limitations of time will prevent me from doing more than refer very briefly to some properties of the optical parts.

It is generally assumed that magnification is the primary function of an objective. But in point of fact the main point is not magnification but resolution. By resolution is meant the power the

objective has of separating and forming correct images of fine detail. That known as the Abbe Diffraction Theory, is the theory on which modern optical calculations are based, and it is safe to say that it was never more fully accepted and never rested on a surer basis than at the present time. There has been much discussion in this country of that theory, and probably a good deal of misconception has arisen from its inapt designation; for the term "Diffraction Theory" is perhaps somewhat unfortunate. I cannot do better than quote the late Lord Rayleigh in reference to this matter. He said: "The special theory initiated by Professor Abbe is usually called the Diffraction Theory, a nomenclature against which it is necessary to protest. Whatever may be the view taken, any theory of resolving power of optical instruments must be a diffraction theory in a certain sense, so that the name is not distinctive. Diffraction is more naturally regarded as the obstacle to fine definition, and not, as with some exponents of Professor Abbe's theory, the machinery by which good definition is brought about."

This very clearly and accurately sums up the position. The Abbe theory tells us that there are two main factors determining resolution: that is, the numerical aperture of the objective used, and the wave-length of the light. Numerical aperture is determined for us by the optician, and it is well known that, with an oil-immersion objective, a numerical aperture of 1.4 is at the present time the practical limit. Metallographers are in a somewhat stronger position, as a mono-bromide of naphthaline immersion objective was, and presumably still is, made by Zeiss, which had a numerical aperture of 1.6. This represents the absolute limit at the present time, and there is no indication that numerical aperture will be increased in this sense by present methods.

The other factor governing resolution is the wave-length of light, and in this connection it must be borne in mind that to resolve a regularly marked structure, the distance between the markings must be more than half a wave-length. Under ordinary conditions of illumination we cannot go very far in the direction of increased resolution unless we have resort to an illuminant such as a mercury vapour lamp, which is rich in blue and violet radiations. There is much room for investigation in this direction, as the ideal illuminant for microscopic work has yet to be found. But I do not know of any one that approaches so nearly to it as the one I have mentioned—the mercury vapour lamp. It suffers only from one disadvantage that I can see, and that is that the differentiation due to staining is not so clearly brought out as when ordinary light is used. But as staining is itself an artificial process, and is simply done to differentiate structures, it only means a certain amount of education to enable us to appreciate the differences, even under the light from this lamp. The only stains which it does not show quite well, or, rather, in which the colour-tint is altered, are those in which red predominates. Any other colour is shown perfectly and in reasonable gradation. The advantages of this illuminant are that it is even and uniform. It has a fairly large area, and can be used therefore for any class of work. Its intensity can be varied within considerable limits by having a resistance in series, so that the current density is altered to suit the particular

work under observation. Further, it is possible, by interposing neutral screens, to vary the light intensity if the electrical method is inconvenient. Owing to its possessing practically no red radiations, its mean wave-length is shorter, and by using suitable screens light which is truly monochromatic, green, blue or violet, can be obtained at will. These lamps are made both in glass and quartz, but the quartz ones are preferable, because they admit of the use of heavier current, with greater luminosity; and further, they have a much longer life. I have exhibited two of these lamps, because I regard them as far in advance of any other form of light available to the microscopist at the present time, whether he is a biologist or a metallographer.

The whole subject of illumination, so far as the illuminant is concerned, needs investigation also, because there is, I think, little doubt that a modification in the intensity of the illumination of any particular object enables us to use a larger light cone than we could do under ordinary circumstances. That is, variation of the intensity is an alternative to the use of the iris diaphragm in the sub-stage of the microscope. But it is in the direction of using invisible radiations in the ultra-violet, or, it may be, radiations which are still shorter than the ultra-violet, that developments in microscopic work are, in my opinion, likely to occur.

There are two other points, which I can only refer to, but which, I trust, may be dealt with more fully in the succeeding papers. One is that, while the resolution limits are so inflexible, that does not by any means apply to mere visibility. By illuminating small particles by means of an annular cone of rays, that is, what is ordinarily known as dark ground illumination, or by illuminating them at right angles to the optic axis of the microscope—what is known as the ultra-microscopic method—particles of a very much smaller order of size can be made visible. But we cannot tell anything about their form, nor can we accurately tell their size. We are only conscious of their mere existence.

Another point to remember is that magnification is definitely limited to something like 750 diameters with microscopes under ordinary conditions, if we want to get the best optical effect. We may, as a matter of convenience, have still higher magnifications, because it is not given to everybody to appreciate fine detail unless an image is somewhat enlarged. But it must be appreciated that any increase beyond 750 or 800 diameters does not result in us seeing anything more. It simply allows us to see the object on a somewhat larger scale. We may therefore summarise as follows:—An object which is much smaller in size than the resolution limit can be rendered visible, providing the light with which it is illuminated is of sufficient intensity, and it is sufficiently different in refractivity from the medium in which it lies. To resolve a series of equi-distant points or lines in an object, their distance apart must exceed half a wave-length of light in the medium in which the object is immersed. Johnstone Stoney has shown that a pair of lines or objects can be separated when their distance apart is rather smaller than the resolution limit required for a number of points or lines in a row. But it should be borne in mind even here that the resolution limits apply if a definite standard of definition is required. An isolated object, or pair of objects, are not so well

defined if they exceed the resolution limits as laid down for recurring structures. It cannot be too fully appreciated that illumination is the keynote of all sound microscopic work, and this applies whether the illumination is by means of visible radiation under ordinary conditions of work, or whether it is in experimental work in which the use of invisible radiations are concerned.

There is much room for research in this direction, and it is to be hoped that this is one of the points which will be seriously taken up. Apart from any question of research, the education of the user is perhaps of vital importance. It is little use for opticians to make great efforts to turn out a satisfactory instrument if the user is incapable of taking advantage of the quality of the optical or other parts. I trust, therefore, that this Symposium will give an impetus in this direction, and that it will help microscope users to realise how much remains to be done.

ADDRESS BY SIR HERBERT JACKSON, K.B.E., F.R.S.

At this stage **Sir Herbert Jackson** delivered an Address, which is printed on page 213 of this Report, owing to an unavoidable delay in preparing it for publication.

Professor F. J. Cheshire, C.B.E., President of the Optical Society, read a paper on "The Mechanical Design of Microscopes."

THE MECHANICAL DESIGN OF MICROSCOPES.

By PROFESSOR F. J. CHESHIRE, C.B.E.,
President of the Optical Society.

The optical industry in this country, as the result of war experience, has been specially recognised by the Government as a key industry, which, in the national interests, therefore, must be encouraged and preserved.

Now the microscope, whether considered from the point of view of the great and increasing demand which it makes upon the highest technical knowledge and skill of the optician and the mechanician, the importance of the work which it is called upon to do, or the great demand for it, stands forth as the most important of all optical instruments. It is thus the keystone of the arch of a key industry. The optical industries of any country which is producing microscopes for which there is a world's demand must be in a healthy and thriving condition. Conversely, any country which fails to produce a microscope to meet the world's demands is very unlikely to have the reputation for producing, on a commercial scale at at any rate, important optical instruments of any kind. The production of the microscope may therefore be accepted as the touchstone of national success in optical activities generally. The importance of this point must be insisted upon—when England can produce microscopes in large numbers for the world's markets, the success of her industries will be assured. Until it does so, that success cannot be accepted as assured.

The development of a mechanical invention which is ultimately required to meet a big demand, usually follows upon well defined lines. At the beginning, when the demand is small, the labour of highly skilled craftsmen is necessary and sufficient for its production, but later, when the demand has increased, it is found that for efficient production the skilled craftsman is no longer sufficient, but special machinery must be put down to replace him. In other words, artistic production is followed by machine production.

As an illustration of production in the artistic period, I cannot do better than tell you a story that was told to me some years ago by the late Dr. Czapski. Dr. Czapski upon one occasion visited Hartnack, the famous maker of microscope water-immersion objectives. He found him sitting on a stool in front of a window, busily engaged assembling the systems of his objectives with the aid of a microscope and a test-object. On the table by his side were a number of grooved sticks, each filled with a number of a particular lens wanted in a certain objective combination. Hartnack, with his great knowledge and skill, was able to look at a critical object and decide from its appearance what lens in a given combination was likely to be responsible for the observed defects. He would then try another and slightly different one in its place. In this way he would try combination after combination, until a satisfactory result was obtained. Occasionally by a fortuitous accident he would obtain an objective much superior in its performance to the general run. These were carefully put on one side, and although Hartnack charged a uniform price for all his objectives, he was very careful to allow none but serious workers to obtain possession of the best quality lenses. Now Abbe realised that this method of production, making such great demands upon unique knowledge and skill, could not possibly meet the growing world's demand for microscope objectives, and therefore that the highly skilled, technical artist must be dispensed with and replaced by mechanical processes capable of producing to a high order of accuracy predetermined elements. This was done, and that success which is now a matter of history, achieved. Some time ago I was discussing this subject with Sir Howard Grubb, and he gave me a remarkable instance from his own experience. He told me that before the war he employed a skilled man to rough out certain lenses by hand at the rate of about a dozen per week. When the war broke out it was realised that something must be done to expedite production, and Sir Howard Grubb invented a special machine, attended by a girl, to perform the necessary operation. The result was that the girl and the machine turned out more than a thousand of these lenses per week.

It follows from what has been said that the microscope must meet not only the demands of the user, it must meet also those of the manufacturer. I suggest, therefore, that a well designed commercial microscope may be defined as one that can be made both accurately and cheaply, and that secures in its use "the greatest happiness of the greatest number." First, it must be a commercial article, one made in great numbers to compete in the markets of the world. Secondly, it must be made accurately and cheaply. These requirements necessitate on the part of the manufacturer specialisation, standardisation, production by repetition machinery

of the most modern types, attended by unskilled labour; the whole of these activities being directed by the highest technical knowledge and skill. Thirdly, a well designed microscope must confer the greatest happiness upon the greatest number of its users. In other words, it must meet to the fullest possible extent, the needs and demands of its users. But these demands are constantly changing and increasing. Demands resulting from war experience, for example, are already of a formidable nature, and are certain to become greater. One fundamental difficulty in design must be noted. A good design having been evolved to meet existing requirements, there is always a strong temptation to meet new requirements by a modification of the old design. In any particular case this may or may not be satisfactory, but one is often inclined to wonder whether this subservience to tradition has not resulted in the perpetuation of designs which, however good they may have been at one time, are now ill-adapted to meet more exacting requirements. A thorough overhaul of the design of the microscope by thoroughly skilled mechanicians, without reference to old and traditional designs, might lead to startling and valuable results. This is a point of great importance to the trade. So long as a manufacturer confines himself to the production of well-known designs, he must of necessity meet with keen competition. Should he, however, be successful in introducing new and valuable features, his chance of success is very greatly increased. This danger of too close an observance of traditional designs is unfortunately enhanced by mass production, because when a manufacturer has laid down expensive plant to produce a given design, it often pays him—or he thinks it does—to buy up patents for improvements upon it, and throw them into the waste-paper basket.

Again, in the elaboration of a standard design we all agree that the faddist must not be considered—the greatest happiness of the greatest number must be sought for. Here, again, the matter is not so easy in practice. We are now told that the bullet which eventually brought down the Zeppelin so ignominiously was, in the first case, refused as the suggestion of a crank. Many valuable suggestions for the improvement of the microscope must also have been turned down for the same reason in the past.

Time, unfortunately, does not permit of any consideration or criticism of the design of the details of the microscope, but there is one matter of some importance to which I should like to draw your attention. In the early days of the microscope the illuminating apparatus was of the simplest kind, generally nothing more than the sky or a common lamp, the light from which was thrown upon the object by a simple mirror. Modern work, however, demands a well-corrected condenser of large aperture—or it may be a dark-ground illuminator—working in conjunction with a small and intense light source accurately adjusted in the axis of the complete illuminating and observing systems. Now this adjustment of the light source is tiresome in the case of an expert, and difficult in the case of a tyro, and, when made, a touch of the mirror, or a slight accidental displacement of the microscope or the lamp, necessitates the work being done again. This difficulty could be largely removed by the simple expedient of resting the microscope and the lamp on geometrical bearings of the three-radiating groove type. In the

case of the microscope these grooves could be cut in the foot of the instrument to rest upon and engage with three studs on the table. This arrangement would be simple and cheap, and would have the further advantage that it would not in any way interfere with the use of the microscope in the usual way—the grooves when not in use would not scratch the table top. In this simple way the placing of the lamp and the microscope in a fixed position with respect to one another, would be secured. It would then only be necessary to fix the mirror, as has been suggested by Mr J. E. Barnard, and the microscopist would, in a few seconds, be able to ensure that a beam of light was being thrown accurately along the axis of his microscope, a necessary condition, for example, of the efficient use of the dark ground illuminator in bacteriological work.

I have not been able to say much, ladies and gentlemen: the time has been too short, but I hope that I have been able to say something which will assist you to realise the national and far-reaching importance of the subject with which we are concerned at this Symposium to-day.

Mr. F. Martin Duncan, President of the Photomicrographic Society, then gave a résumé of his paper, "Some Notes on the History and Design of Photomicrographic Apparatus."

SOME NOTES ON THE HISTORY AND DESIGN OF PHOTOMICROGRAPHIC APPARATUS.

By F. Martin Duncan, F.R.M.S., F.R.P.S., F.Z.S.
President of the Photomicrographic Society.

No survey of the present position of microscopy would be complete without a reference to the very important part which photomicrography plays as a means of accurately recording the various objects which are submitted to microscopic examination. To the investigator in bacteriology, biology, and metallography, a photomicrographic apparatus is to-day an essential part of his microscopic outfit, and therefore the consideration of the design of such apparatus has become a matter of prime importance.

Scientific workers were quick to realise the value of photography as a means of obtaining an unbiased graphic record of their observations, and it was only the limitations and technical difficulties of the early processes that prevented its wider use. From the time of its first discovery there have been microscopists who have employed photography in preference to the pencil. Thus in 1845 Doune and Foucault illustrated their "Atlas of Microscopic Anatomy" by etchings from photomicrographs taken on Daguerreotype plates, while as early as 1835 Fox-Talbot had obtained images of objects in the solar microscope by means of his recently discovered process. It would be out of place here to enter into a description of the early pioneers of photography, intensely interesting though the subject be, but in passing one cannot help feeling proud of the fact that the discovery of photography was due to British and French scientists alone, and that the first to apply it successfully to the recording of microscopic objects were Fox-Talbot in England, Daguerre in France, and Draper in America. And since those first days of the history of photomicrography, it has been in France, in Great Britain, and in America that the greatest experts, the most notable advances and inventions, and the most perfect apparatus for photomicrography have been produced.*

Naturally the apparatus used in the early stages of the application of photography to microscopy was of a somewhat crude character. The earliest cameras were little more than light-tight boxes, while many of the pioneers dispensed with any form of camera at all, the

* For a short account and early bibliography see an article entitled "Chapters in Photomicrography," which I contributed to the *British Journal Photographic Almanac* for 1903, pp. 691-725.

eye-piece end of the microscope being inserted through a circular hole in the wall of the dark-room, and the Daguerreotype plate, or the wet collodion plate placed upon a board in the dark-room, on which the image formed by the microscope had previously been focussed. Considerable difficulties had to be overcome in obtaining the correct adjustment that would yield a sharp, crisp image, owing to the, at that time, imperfect corrections of microscope objectives; but gradually from such crude beginnings the practice of photomicrography has attained to its present high standard of technique. That the rapid improvement and high standard of perfection to which microscope objectives, eye-pieces, and substage condensers have reached are largely due to the investigations and labours of Abbe, Schott, and Zeiss, all microscopists will readily admit; but that is about all, though admittedly it is a very important contribution, that can honestly be claimed by Germany as her share towards the perfection of photomicrography.

I know that opinions are very sharply divided on the subject of the microscope stand as made by British and German manufacturers, and I feel that much of the criticism that has been levelled at the British manufacturers is grossly unfair and inaccurate, because in nine cases out of ten the would-be critic is already prejudiced in favour of the German, has not a thorough technical knowledge or experience, and frequently has never used a really first-class British stand. I am quite ready to admit that the British maker has turned out some very poor models, but so has the German; but because the Britisher has produced some cheap models of poor quality, surely that is no reason for damning at sight everything he produces. You are not going to encourage home enterprise or industry by such methods. I have now used the microscope practically daily for over thirty years in my biological investigations, and during that time models by all the leading British and Continental manufacturers have passed through my hands, and have been, I hope and believe, honestly, critically, and impartially tested. Out of that long experience I am bound to say that for comfort in working, rigidity, and perfection in design and workmanship, I have yet to see the German or Continental model that will touch the very best productions of our leading British manufacturers. In no branch of microscopy is the superiority of the first-class British microscope stand more readily demonstrated and realised than in critical high-power photomicrography, for to produce the best results, rigidity, whether in the vertical or horizontal position of the microscope body, and ease of manipulation of the mechanism of the substage and the top or object stage are factors of vital importance—factors which are not present in the horseshoe foot, or the finicky studs and knobs provided for the adjustment of substage and substage-condenser, and mechanical stage, in the German models. Even the large Zeiss model specially designed by that firm for photomicrography, though of good workmanship, suffers from these inherent defects of the Continental model, its substage mechanism being very cramped, and the mechanical stage provided with wretchedly small pinion heads.

The microscope stand intended for critical photomicrography and original research should have a solidly cast broad tripod foot, such as is present in the large research model of Swift, the R.M.S model

of Baker, or the Royal and Van Heurck models of Watson. The focussing of the substage condenser should be by a stout pinion of such a length that the hand does not have to grope for it beneath the stage, and should be provided with a good milled head. Fairly stout pinions and milled heads should also be provided for controlling the vertical and transverse movements of the mechanical stage, while the body-tube should be of large diameter to admit the use of low-power objectives required when photographing comparatively large fields.

Between the years 1889 and 1899, Messrs. Swift and Messrs. Baker produced two very fine photomicrographic cameras that might well to-day rank as standard models for critical high-power work. That made by Messrs. Swift incorporated designs suggested by Mr. Andrew Pringle, and that by Messrs. Baker the ideas of the late Mr. C. Lees Curties—both experienced microscopists and photomicrographers. The essential features of each outfit are very similar, and consist of (1) a long solid baseboard forming a rigid foundation on which the whole apparatus is built; (2) a substantial square-bellows camera travelling on a wide base and capable of considerable extension; and (3) a substantial turntable for the support of the microscope condensers and illuminant. On account of the wide, solid base on which the square-bellows camera travelled, the camera could be extended to its fullest degree and used in that position without fear of vibration during long exposures. With such apparatus the formidable task of obtaining sharp negatives at a magnification of upward of two thousand diameters linear, could be accomplished with certainty, and, given the necessary technical knowledge, celerity and ease. It is no light task to be called upon to produce large numbers of photomicrographic negatives at such high magnifications, when the work has to be carried out in a house past which heavy street traffic is continually travelling, yet such formed a part of my duties during the terrible years of the war, and was made possible only by the use of apparatus of the design I have just described. Before the work was placed in my hands, attempts had been made to carry it out with photomicrographic apparatus mounted on iron rods, the typical German design; and therefore, of course, supposed to be vastly superior to anything British. The failure was due to no want of skill on the part of the users of the apparatus, but to its inherent faulty design, for it is obvious that vibration will be more readily conducted and its amplitude increased along the rods than through a solid base. Both from long pre-war experience and from the result obtained in that part of my war work just described, I feel that I am fully justified in stating that the right design for photomicrographic apparatus intended for critical high-power work is on the lines of the Pringle-Lees Curties models, or the more recent designs of Singer made by Messrs. Watson and Sons, and of Barnard, made by Messrs. Baker.

It frequently is necessary to take photomicrographs with the microscope in the vertical position, and here again to employ a camera clamped to an upright iron rod is asking for trouble, to say the least, yet that is the design dear to the heart of the German manufacturer. Many years ago now, Messrs. Watson and Sons placed on the market a vertical model made to the design of the veteran microscopist, the

late Dr. Van Heurck. The apparatus consists of a vertical box-form camera supported on four stout square legs, between which, and immediately beneath the camera, the microscope is placed. The whole is very rigid, and we all know the magnificent work Dr. Van Heurck and others produced with it. The chief objection, and, when considered on optical grounds, to my mind not a very real one, is that it precludes the employment of extended camera lengths. But ten inches from the eye lens of the eye-piece to the focussing screen of the camera is, I believe, the ideal extension for critical work with modern objectives. In the *Journal of the Royal Microscopical Society* for 1916, pages 258-9, I have figured and described a simple home-made vertical stand to carry microscope and camera, and although there shown as used for stereo-photomicrography, I have since used it successfully for high-power work with the monocular microscope with magnifications up to two thousand diameters.

A vertical apparatus of good, rigid design is of such importance for a great deal of microscopical research work that is being carried out to-day, that it is a matter deserving the immediate and serious consideration of our British manufacturers.

Dr. Charles Singer presented the following paper on "The Earliest Steps in the Invention of the Microscope." The paper was taken as read.

THE EARLIEST STEPS IN THE INVENTION OF THE MICROSCOPE.

By Charles Singer, M.A., M.D.Oxford, F.R.C.P.Lond., F.S.A.

The microscopes and the microscopic work of the classical observers, Leeuwenhoek, Malpighi, Hooke, and Kircher, have been frequently described and figured. These descriptions are readily accessible, and I shall therefore confine myself to the earliest stages in the discovery of the microscope, which is, of course, intimately connected with the invention of the telescope. About these early stages vague statements are often made, but the actual data do not seem to have been put together.

(1) *Euclid* (third century, B.C.), in his *Optics*, considered that light passed in straight lines, and regarded an object seen as formed by a cone with its base at the object and the apex at the eye. The Euclidian origin of this work is disputed by some, who hold that is is by Theon of Alexandria, who lived in the fourth century, A.D., and was perhaps the father of Hypatia. The most recent edition is by G. Ovio, *L'Ottica di Euclide*, Milan, 1918.

(2) *Ptolemy* (died about 155 A.D.), in his *Optics*, began the study of refraction, and applied the experimental method to this subject. He showed that luminous rays, in passing from one medium to another are deflected, and he attempted to measure the deflection. This work of Ptolemy was written in Greek, and has been lost. It was translated from Greek into Arabic, and, in the twelfth century, from Arabic into Latin. Only the Latin version survives, and its attribution to Ptolemy is doubtful. The best edition is by G. Govi, Turin.

(3) *Alhazen* (Abu Ali Al-Hazan Ibn Alhasan, 965-1038), was an Arab of Basra, who abstracted the work of the older Greek optical writers. He devoted much space and skill to the development of the effects of curved mirrors. He had a fairly clear notion of the nature of refraction, and improved the apparatus of Ptolemy for measuring the angle of refraction in different media. He had

ideas on the structure of the eye that were an improvement on those of his predecessors, but he had little knowledge of lenses, except in connection with that organ. He does, however, refer to the magnifying power of segments of a glass sphere. He considered that vision resulted from rays coming to the eye from the object, and opposed the view, which held the field till the seventeenth century and later, that explained vision as a result of something emanating from the eye. There are editions of Alhazen's work printed in the sixteenth century. These represent a translation into Latin by an unknown writer of the late twelfth or early thirteenth century (*see* 4).

(4) *Witelo* (first half of the thirteenth century) was a Pole, who studied in great detail the work of Alhazen. His own work grew out of this, and is perhaps an improvement on it. Thus he drew up a table of refractions for the three media—air, water, and glass—from which it could be seen that the angle of refraction did not vary according to the angle of incidence. It is doubtful, however, to what extent these tables were original or the results of direct observation. The works of Alhazen and of Witelo were printed together by F. Risner at Bale, 1572. An interesting account of Witelo, together with a reprint of his *Perspectiva* from the MSS. has been recently set forth by Clemens Bauemker in his *Beiträge zur Geschichte der Philosophie des Mittelalters*, Munich, 1908.

(5) *Roger Bacon* (1214-1294) accomplished real advances in the knowledge of optics. His work was based primarily on Latin translations of Arabian writers, and especially on Witelo's version of Alhazen. He is distinguished from his predecessors, however, by his clear conception of the value of experiment, and by the evidence in his works that, having made a serious and continuous effort to discover the laws of the refraction and reflection, he sought to apply his knowledge to the improvement of the power of vision. In this he is a real pioneer, and is in the truest sense the father of microscopy.

But it is easy to exaggerate the claims of Bacon, and the wildest statements are often made about his discoveries. It is a fact that there is no evidence that he ever made a telescope nor any microscope, save a simple one. But he had a clear, though not wholly accurate idea of the nature and properties of lenses, and, groping with the instinct of genius, he did vaguely foresee both telescope and microscope. The following passages will serve to indicate the stage he had reached in optical knowledge. I have purposely selected passages containing some errors. It will be observed that in the first of these passages Bacon refers to and figures the *object* as though it were itself in the denser medium of which the lens is composed. In doing this he is confusing the optical action of a lens with that of a liquid in which an object is immersed. The optical results of immersion in a liquid had been investigated by his predecessors, and were perhaps familiar to Aristotle.

"If anyone examines letters and other minute objects through the medium of crystal or glass or other transparent substance, if it be shaped like the lesser segment of a sphere, with the convex side towards the eye, and the eye being in the air, he will see the

letters far better, and they will seem larger to him. For, according to Canon 5 (*see* Fig. 1) concerning a spherical medium beneath which the object is placed, the centre being beyond the object, the convexity being towards the eye, all causes agree to increase the size, for the angle in which it is seen is greater, the image is greater, and the position of the image is nearer, because the object is between the eye and the centre. For this reason such an instrument is useful to old persons and to those with weak eyes. For they can see any letter, however small, if magnified enough. But if a larger segment of a sphere be employed, then, according to Canon 6

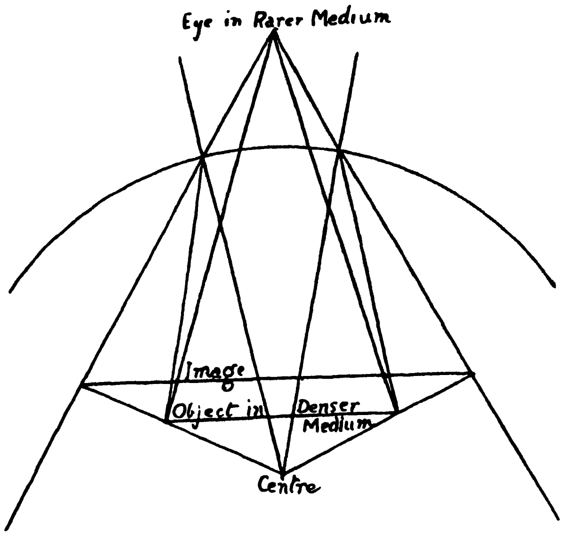


FIG. 1

(Fig. 2), the size of the angle is increased, and also the size of the image, but propinquity is lost because the position of the image is beyond the object, the reason being that the centre of the sphere is between the eye and the object seen. Therefore such an instrument is not of so much use as the smaller portion of a sphere."

"Objects are greater when the vision is refracted; for it easily appears by the above-mentioned canons that very large objects may seem to be very small and conversely, and those at a great distance away may seem very near and conversely. For we can so form glasses and so arrange them with regard to our sight and to objects that the rays are refracted and deflected to any place we wish, so that we see the object near at hand or far away beneath whatever angle we desire. And so we can read the smallest letters or count grains of sand or dust from an incredible distance, owing to the magnitude of the angle beneath which we see them, while we can scarcely see the largest objects close at hand, owing to the smallness of the angle beneath which we view them: for distance does not affect this kind of vision save *per accidens*, but the size of the angle

(does so affect it). So a boy can appear a giant, a man seem a mountain, and in any size of angle whatever, just as we can see a man under so large an angle like a mountain and as near as we desire. So a small army might seem very large, and though far away appear near, and conversely: so too we could make sun, moon, and stars apparently descend here below, and similarly appear above the heads of our enemies, and many other similar marvels could be brought to pass, so that the ignorant mortal mind could not endure the truth." (*Opus Majus*, Part V).

"And what is causally manifest with regard to double refraction we can verify in many ways by the results of experiment. For if anyone holds a crystal ball or a round urinal flask filled with water in the strong rays of the sun, standing by a window in face of the

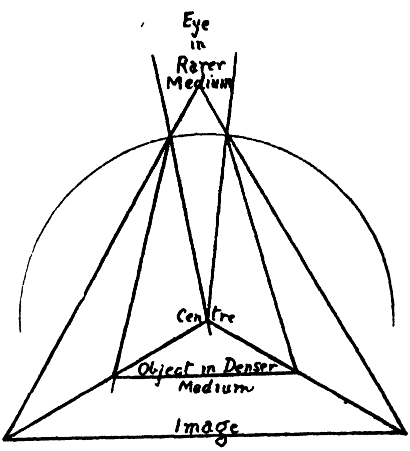


FIG 2.

rays, he will find a point in the air between himself and the flask at which point, if any easily combustible substance is placed, it will catch fire and burn, which would be impossible unless we suppose a double refraction. For a ray of the sun coming from a point in the sun through the centre of the flask is not refracted, because it falls perpendicularly on flask, water, and air, passing through the centre of each (Fig. 3). . . . But all the (other) rays which are given forth at the same point in the sun from which this perpendicular ray comes are necessarily refracted on the body of the flask, because they fall at oblique angles, and since the flask is denser than air, the refraction passes between the straight path and the perpendicular drawn from the point of refraction to the centre of the flask. And when it passes out again into the air, then, since it comes upon a less dense body, the straight path passes between the refraction and the perpendicular drawn from the point of refraction, so that the refracted ray may fall upon the first perpendicular which comes without refraction from the sun. And since an infinite number of rays are given off from the same

point of the sun, and one only falls perpendicularly on the flask, all the others are refracted and meet at one point on the perpendicular ray which is given off along with them from the sun, and this point is the point of combustion, because on it are collected an infinite number of rays, and the concentration of light causes combustion. But this concentration would not take place except by double refraction, as shown in the diagram." (*Opus Majus*, Part VII).

"Glasses (*perspicua*) can be so constructed that objects at a very great distance appear to be quite close at hand, and conversely. Thus we read the smallest letters from an incredible distance, number objects, however small, and make the stars appear as near as we wish. . . . Also objects can be made to appear so that the

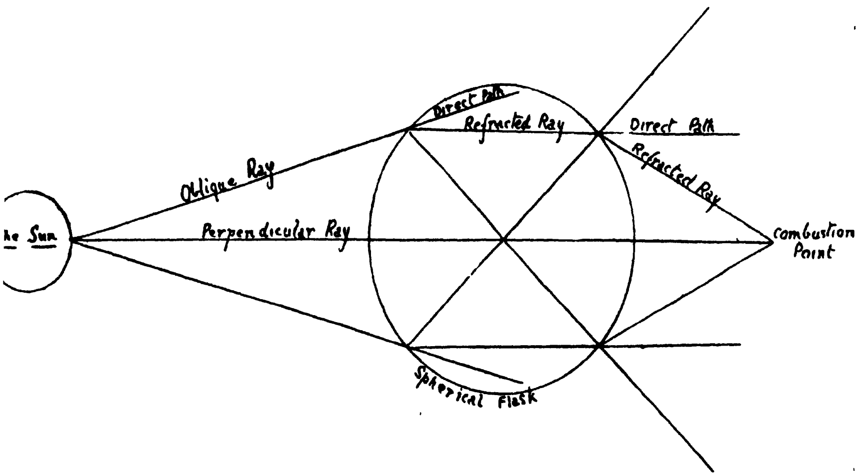


FIG 3.

greatest seems the least, and conversely; what are high appear low and short, and conversely; and what is hidden appears manifest. . . But among the more subtle powers of construction is this of directing and concentrating rays by means of (instruments of) different forms and reflections at any distance we wish, where whatever is subjected to them is burned. . . . But greater than any such design or purpose is that the heavens might be portrayed in all their length and breadth on a corporeal figure moving with their diurnal motion, and this would be worth a whole kingdom to a wise man. Let this, then, be sufficient as an example, although an infinite number of other marvels could be set forth." (*De Secretis Operibus Artis et Naturae.*)

It is a remarkable thing that no complete edition of the works of Roger Bacon has ever been prepared, nor any important work by him translated into English. The above passages I have translated from J. H. Bridges, *The Opus Majus of Roger Bacon*, Oxford, 1897, and J. S. Brewer, *Fratris Roger Bacon opera quaedam hactenus inedita*, London, 1859.

(5) *John Peckham* (died 1292), Archbishop of Canterbury, was the author of a work on optics entitled *Perspectiva communis.* His views were very similar to, and, perhaps, taken from, Bacon. He is important only as having drawn wide attention to optical principles. His work exists in a number of manuscripts, and has often been printed. The first edition is dated from Milan, 1482.

(6) The names of Salvino d'Amarto degli Amarti of Florence and Alessandro de Spina of Pisa (both circa 1300) have become associated with the special application of lenses for use as spectacles. Lenses, as we have seen, were known to Roger Bacon, who suggested also their use in aiding vision. D'Amarto and Spina applied the principle thus suggested. From about 1300 onward convex lenses for use as spectacles were well known.

The question of the invention of spectacles has been frequently discussed. One of the latest writers who has traversed this field is V. Rocchi, *Appunti di storia critica del microscopio*, in the *Revists di Storia critica delle Scienze Mediche e Naturali*, January, 1913.

(7) *Leonardo da Vinci* (1452-1519) had sounder ideas than any of his predecessors on the structure of the eye, on binocular vision, on refraction and diffraction. He developed a practical *camera obscura*, and gives a hint of a "glass to see the moon enlarged." His work, though original and valuable, remained inaccessible for nearly four centuries, and had no influence on his contemporaries.

Leonardo left his scientific remains in a state of confusion, and they have suffered much by time and misuse. It is impossible to give a bibliography here, but his optical results are summarised by E. Solmi, *Leonardo da Vinci e il metodo sperimentale nelle ricerche fisiche*, in the *Atti e memorie della R. Accademia Virgiliano di Mantova*, Mantua, 1905, and by O. Werner, *Zur Physik Leonardo da Vincis*, Berlin, 1911.

(8) *Girolamo Fracastoro* (1478?-1553) was a suggestive writer who devoted considerable space to a rather confused account of refraction. In the course of this discussion he has the following passage:—"(Not only the character but) also the position of the medium affects the appearance of the objects seen, as may be observed with spectacle lenses (*in specillis ocularibus*). For if the lens be placed midway between eye and object, it appears much larger than if the lens is made to approach the object or the eye. (*Homocentrica* II, 8). . . . Glasses (*specilla ocularia*) may be arranged of such density that if anyone looks through them at the moon or at any star they appear near and hardly higher than the steeples. (*Homocentrica*, III, 23)." It is possible that he was here contemplating a bilenticular apparatus. The *Homocentrica* in which these passages occur was first printed at Venice in 1538. The scientific value of this work is discussed by the present writer in an article in the *Annals of Medical History*, Vol. I, p. 1, New York, 1917

(8) *Francesco Maurolico* (1494-1575) was perhaps the first after Roger Bacon to attempt a mathematical analysis of the optics of the lens. He is thus the predecessor of Kepler. His work, *Photismi de lumine et umbra*, was printed at Venice in 1575.

(9) *Leonard Digges* (died 1571 ?) was the first to whom can be definitely attributed the construction of a bilenticular system. The evidence for this statement rests on the following passage in a work by his son, Thomas Digges (died 1595):—

"Marueylouse are the conclusions that may be perfourmed by glasses concaue and conuex of circulare and parabolicall fourmes, using for multiplication of beames sometime the ayde of glasses transparent, which by fraction should unite or dissipate the images or figures presented by the reflection of other. By these kinds of glasses or rather frames of them, placed in due angles, ye may not only set out the proportion of an whole region, you represent before your eye the lively image of euery towne, village, etc., and that in as little or great space or place as ye will prescribe, but also augment and dilate any parcell thereof, so that whereas at the firste apparance an whole towne shall present it selfe so small and compacte together that ye shall not discerne any difference of streates, ye may by applycation of glasses in due proportion cause any peculiare house or roume thereof dilate, and shew it selfe in as ample fourme as the whole towne first appeared, so that ye shall discerne any trifle or reade any letter lying there open, especially if the sonne beames may come unto it, as playnly as if you wer corporally present, although it be distante from you as farre as eye can discrye. But of these conclusions I minde not here more to intreate, hauing at large in a volume by it selfe opened the miraculous effectes of perspective glasses." Digges's system appears to have been combined in some manner with a *camera obscura*. Unfortunately, his further description of it was never published. The work of Thomas Digges in which this passage occurs is entitled *A Geometrical Practise named Pantometria*, and was printed in London in 1571.

(10) *Gianbattista della Porta* (1540-1615) is the first to whom can be attributed the actual combination of lenses in the form of a microscope. This statement rests on the evidence of the following passages in his *Magia naturalis*:—"Concave lenses enable one to see far off more clearly, while convex ones make near objects more discernible." He was apparently myopic, for he goes on to say that "with a concave lens you see things afar smaller but plainer; with a convex lens you see them larger but less distinct. If, however, you know how to combine the two sorts properly, you will see near and far both large and clear." In later years, when the microscope became a recognised instrument, much larger claims were made by and for Porta, but there is no real evidence that he made any effective practical application of his idea. The *Magia naturalis* was first printed at Naples in 1558, but the passages in question do not occur in it, nor in any edition of the work that appeared before that of 1588.

(11) *Zacharias*, son of Jan, and known as Jansen (1580-16 ?), of Middelburg, is usually regarded as the first who actually constructed a microscope. His first attempt was the result of an

accident. It appears that while still a lad and at work in the shop of his father, who was a spectacle maker, he happened to place two lenses in a tube and found that they acted as a microscope or telescope. Effective instruments were constructed by him in the first decade of the seventeenth century. The evidence that Jansen was really the first constructor of these bilenticular instruments rests on the testimony of Willem Boreel (1591-1668), the Dutch Ambassador to France. Boreel's evidence is given in a letter by him to Pierre Borel (1620-1671), which runs as follows:—

"I am a native of Middelburg, the capital of Zeeland, and close to the house where I was born . . . there lived in the year 1591 a certain spectacle maker, Hans by name. His wife, Maria, had a son Zacharias, whom I knew very well, because as a neighbour and from a tender age I constantly went in and out playing with him. This Hans, or Johannes, with his son Zacharias, as I have often heard, were the first to invent microscopes, which they presented to Prince Maurice, the governor and supreme commander of the united Dutch forces, and were rewarded with some honorarium. Similarly, they afterwards offered a microscope to the Austrian Archduke Albert, supreme governor of Holland. When I was Ambassador to England in the year 1619, the Dutchman Cornelius Drebbel of Alkomar, a man familiar with many secrets of nature, who was serving there as mathematician to King James, and was well known to me, showed me that very instrument which the Archduke had presented as a gift to Drebbel, namely, the microscope of Zacharias himself. Nor was it (as they are now seen) with a short tube, but nearly two and a-half feet long, and the tube was of gilded brass, two fingers breadth in diameter, and supported on three dolphins formed also of brass. At its base was an ebony disc, containing shreds or some minute objects which we inspected from above, and their forms were so magnified as to seem almost miraculous." This passage is contained in a work by Pierre Borel, *De vero telescopii inventore cum brevi omnium conspiciliorum historia*, The Hague, 1655.

(12) *Jan Lippershey* of Wessel (flourished 1608) is another candidate for the same honours as Zacharias. In October, 1608, a man named Lippershey applied at the Hague for a monopoly in the making of a bilenticular apparatus for examining objects at a distance. Even at that date, however, it appears from the evidence that such instruments were already known. The story of Lippershey's discovery is suspiciously like that told of Zacharias. The application and findings of the committee that sat on it were still in existence in the early part of the nineteenth century, and were published by J. H. van Swinden. *See* S. Moll, *Journal of the Royal Institution*, Vol. 1, 1831.

(13) *Jacob Andrianzoon*, otherwise *James Metius* of Alkmaar, was a younger brother of a distinguished geometrician. Of him Descartes, in his *Dioptrique*, published in 1637, writes as follows:—"It is about 30 years since one named Jacques Metius, an unlearned man, but one who loved to make mirrors and burning glasses, having by him glasses of various shape, thought of looking through two of them, of which one was convex, and the other concave, and he

luckily put them in the ends of a tube, and thus the first telescopes were made." Metius also applied for a patent, and a copy of his application has survived among the MSS. of Christion Huygens (1629-1695).

(14) *Galileo* (1564-1642) was the effective discoverer of the microscope, a discovery which, as in the other cases, was bound up with that of the telescope. The event may be referred to the early part of 1609, and the story may be told in a translation of his own words:—

"About ten months ago," he says, "a rumour reached me of an ocular instrument made by a certain Dutchman by means of which an object could be made to appear distinct and near to an eye that looked through it, although it was really far away. . . . And so I considered the desirability of investigating the method, and I reflected on the means by which I might come to the invention of a similar instrument. A little later, making use of the doctrine of refractions, I first prepared a leaden tube, at the ends of which were placed two lenses, each of them flat on one side, and as to the other side I fashioned one concave and the other convex. Then, moving the eye to the concave one, I saw the objects fairly large and nearer, for they appeared three times nearer and nine times larger than when they were observed by the naked eye. Soon after I made another more exactly, representing objects more than sixty times larger. At length, sparing no labour and no expense, I got to the point that I could construct an excellent instrument so that things seen through it appeared almost a thousand times greater and more than thirty-fold nearer than if observed by the naked eye." (*Siderius Nuncius*, Venice, 1610).

In another work he says: "Some would tell me that it is of no little help in the discovery and resolution of a problem to be first of all in some way aware of the true conclusion and certain of not being in search of the impossible, and that therefore the knowledge and the certainty that the microscope had indeed been invented had been of such help to me that perchance without that I should not have discovered it. To this I reply that the help rendered me by the knowledge did indeed stimulate me to apply myself to the notion, and it may be that without this I should never have thought of it. Beyond this I do not believe that knowledge to have facilitated the invention. But, after all, the solution of a problem, thought out and defined, is a work of some skill, and we are not certain that the Dutchman, the first inventor of the telescope, was not a simple maker of ordinary lenses who, casually arranging glasses of various sorts, happened to look through the combination of a convex and a concave one placed at various distances from the eye and in this way observed the effect that followed thereon. But I, moved by the knowledge given, discovered it by a process of reasoning." (*Il saggiatore*, Rome, 1623.)

(15) Galileo's account of the path of light in the bilenticular system is unsatisfactory, but was improved by Kepler in his *Dioptrice* (Cologne, 1611), who at the same time suggested that form of microscope consisting of two convex lenses which has developed as our modern instrument.

Professor A. E. Conrady contributed some "Notes on Microscopical Optics," which were communicated by Professor Alfred W. Porter, F.R.S.

NOTES ON MICROSCOPICAL OPTICS.

By A. E. Conrady.

It is manifestly impossible to give an exhaustive treatise on microscopical optics in a short paper, but a brief indication of what has been done and what is likely to be accomplished in the near future may be acceptable.

The resolving and defining power of the microscope depends primarily on the high correction of spherical aberration in cones of rays of very large angular aperture. The first approximation methods which are useful in arriving at preliminary designs of telescope objectives will only give rough indications of the required forms of components even in the lower powers of microscope objectives, and they are quite useless in the case of the higher powers.

Exact trigonometrical ray-tracing must therefore form the foundation of the designer's work. It is not, however, desirable to depend entirely upon this method, for the real desideratum in every lens system is that all the light from an object-point should reach the image point along paths of the same optical length, and according to the classical limit recommended by the late Lord Rayleigh, this equality of optical paths should not be departed from to a greater extent than $\frac{1}{4}$ wave-length, say five one-millionth of an inch. It used to be thought by practical opticians that this represented a perfectly absurd and unattainable degree of perfection, but I showed long ago (Monthly Notices R.A.S., April, 1905), that so far is this from being true that the Rayleigh limit really represents a far more generous allowance, in the ratio of about 4 to 1, than the union of the geometrical rays within a "circle of confusion" equal to the resolving power of an objective, which latter condition was looked upon as practicable. Quite recently the fulfilment of the Rayleigh condition in good telescope and microscope objectives has been put to the direct experimental proof by that valuable innovation: the Hilger Lens-Interferometer. In the paper quoted above I gave a trigonometrically exact method of *determining* the phase-relation in which rays arrive at a focus. I had used the method for about 10 years at the time of its publication, and all my designs of microscope objectives are based on its use: but up to the time when I began lecturing at the Imperial College I was probably the only designer who took advantage of this method, which is not only the soundest from the theoretical point of view, but also by far the easiest and quickest. As it gives the exact amount of spherical

aberration arising at each surface in the absolute measure of wave-lengths, it also enables a designer to avoid the unnecessary piling up of huge aberrations such as are met with in the lens systems designed by purely geometrical ray-tracing.

Recently (Monthly Notices, June, 1919), I have rounded off this earlier work by determining the complete light-distribution in the "spurious disc" which results when residuals of aberration are present, so that the designer using the optical path method can now state definitely to what extent the image points obtained with a given system fall short of the full brightness and sharpness which would result in a theoretically perfect instrument.

The chromatic aberration of microscopic objectives is also best and most conveniently determined in terms of differences of optical paths (Monthly Notices, January and March, 1904). By applying the simple formulae to both marginal and paraxial rays, a reliable measure of the higher chromatic aberrations, the so-called spherical variation of chromatic correction, is obtained, and this can then, by suitable alterations of lens curvatures, etc., be kept within those narrow limits which distinguish "semi-apochromatic" objectives from earlier types in which this variation frequently reached very serious amounts.

A microscope objective perfectly free from spherical and chromatic aberration may yet be absolutely useless for practical purposes on account of such amounts of coma in the images of extra-axial object points that sharp definition is limited to an almost infinitesimally small area in the exact centre of the field. One of Abbe's first attempts at the designing of microscope objectives purely by calculation appears to have resulted in a particularly bad specimen of this type. The search for the cause of the defect led him to the independent discovery of the famous "Sine-Condition," also announced almost simultaneously by Helmholtz, and previously discovered—without attracting the attention of opticians—by Clausius. In an approximate algebraical form it also figured as the second of the famous 5 conditions of Seidel. The realisation of its immense value, however, dates undoubtedly from the announcements by Abbe and Helmholtz in 1873. Since that time it has saved an incalculable amount of time and trouble to the designers of telescope and microscope objectives, as it indicates the presence or absence of coma in the central part of the field by a simple comparison of figures taken directly from the trigonometrical computations. I gave a simple and fairly exhaustive proof and discussion of this theorem in Monthly Notices for March, 1905, and to that paper those interested may refer.

If, and only if, the foregoing defects (spherical and chromatic aberration within the Rayleigh limit and coma) are properly corrected, then another defect of all ordinary lens systems will become obvious and objectionable, *viz.*, the secondary spectrum. This is due to the fact that, as compared with ordinary crown glasses, the heavy flint glasses which have to be used to compensate the primary chromatic aberration disperse the blue end of the spectrum too much and the red end too little. The result is that flint lenses of the proper power to secure achromatism for the brightest yellow and green region of the spectrum overcorrect the dispersion of the crown

in the blue and violet end and undercorrect it in the orange and red end. As the crown lenses alone would bring violet to a shortest and red to a longest focus, the effect is that the achromatic combination brings both ends of the spectrum to a longer focus than its central part. Therefore there is a minimum distance of the focus for yellow-green, and at that focus the light from both ends of the spectrum is diffused, and causes a halo of a purple or claret tint. This halo is objectionable even in visual observations, because it falsifies the true colour of the observed objects, but the difference of focus to which it is due becomes a grave defect when the object is to be photographed, unless a strong screen is used which cuts off both ends of the spectrum, but more particularly the dark blue and violet light. Such a screen greatly increases the required time of exposure, and may be inadmissible in the case of stained or naturally strongly coloured objects, because these may be either opaque or too transparent to yellow-green light.

The attempts to produce varieties of *glass* free from this secondary spectrum have been unsuccessful as far as the microscope is concerned, for the existing crowns and flints with proportional dispersion have so little difference in dispersive power that an impracticable number of lenses would have to be used to secure the desired effect. We therefore still depend on the material whose value for this purpose was discovered by Abbe, the natural mineral fluorite, used instead of crown glass in combination with heavy crown glasses or very *light* flint glasses in place of ordinary *dense* flint glass. It was by the use of fluorite that Abbe produced the apochromatic objectives, and fluorite of good optical quality must be used to this day to secure the result. Apart from the difficulty of finding this material there is no obstacle to the designing by exact calculation of apochromatic objectives.

I now come to a defect of nearly all microscope objectives, and especially of highly corrected ones, which is well known to all practical microscopists, namely the pronounced curvature of the field, invariably in the sense of requiring a shortening of the distance from object to lens in order to obtain a sharp focus in the outer parts of the field of view. The general theory of the primary aberrations of oblique pencils shows that any lens system when freed from astigmatism will have the curvature of field defined by the Petzval theorem, and that in the presence of astigmatism the two focal lines which then represent the strongest concentration of the light always lie both on the same side of the Petzval curve and at distances from it which are in the approximate ratio of three to one. When the astigmatism is undercorrected the natural curvature of the field defined by the Petzval equation becomes aggravated whilst overcorrected astigmatism tends to flatten the field, and is deliberately introduced for this purpose in ordinary photographic objectives. The presence of considerable amounts of astigmatism, of course, renders really sharp marginal images impossible in either case, so that its absence or better still a modest amount of overcorrected astigmatism must be regarded as the ideal in microscope objectives. Unfortunately this desirable state cannot be reached in the existing types of objectives. The binary low power objectives up to the ordinary one inch and 2/3 inch come nearest to it, and are therefore justly liked

by microscopists for all work for which they are sufficiently powerful. In the ordinary ternary objectives of the 1/6 inch type, with approximately plano-convex components, the curvature of the field is also of reasonably moderate amount. But it is a general experience that highly corrected objectives are very much worse as regards curvature of field. In the light of my most recent work on the general theory of lenses (Monthly Notices, November, 1919), this curious and objectionable peculiarity is easily explained, and becomes revealed as a *necessary* consequence of high spherical and chromatic correction if the usual number of components is adhered to. In the Lister and Amici types of ordinary objectives, which are fairly satisfactory as regards curvature of the field, the front lens is of such a form as to produce strong outward coma and there is in the back lens or lenses a corresponding amount of inward coma. The simple extensions of Seidel's theory given in the paper last referred to show that this is the state of affairs which tends to diminish undercorrected astigmatism or even to reverse it into the more desirable over-corrected form. High correction of the zonal spherical aberration, and to a still greater extent complete removal of the spherical variation of chromatic correction necessitate a more or less complete reversal of the coma effects in front and back components. In other words, with the usual types of objectives, reduction of curvature and apochromatic or semiapochromatic correction are completely antagonistic and incompatible: what benefits one correction is detrimental to the other. Fortunately the extended theory also indicates a way out of this dilemma. It appears fairly certain that by building the objective itself on the lines required by the apochromatic condition, but leaving it spherically undercorrected, perhaps also chromatically overcorrected to a moderate extent, and with a considerable amount of outward coma (this is the most important), and by correcting these residuals in a *widely separated* additional back lens, it will be possible to combine moderate curvature of field with apochromatic perfection and thus to remove the worst outstanding defect of the best objectives.

Condensers for the proper well-regulated *illumination* of microscopic objects are identical in optical design with objectives, the only difference being that the light passes through in the reverse direction and that a lower degree of correction is sufficient not only on theoretical but also on practical grounds, for nearly always condensers are used in conjunction with the " plane " mirror, which invariably is very far from optical perfection, and so introduces irregular aberrations of unknown magnitude and kind, and moreover the light from the condenser has to pass through the slide on which the object is placed. This slide is practically little better than window glass as far as optical quality and perfection of surfaces is concerned, and the great variation in thickness is another source of imperfection, especially with dry condensers of high N.A.

Moderate amounts of residual aberrations in condensers can always be effectively neutralised by using a sufficiently large source of light of uniform brightness or by magnifying the source by a sufficiently well-corrected " bull's-eye," if the source of light is naturally small.

A great and very serious defect in the construction of nearly all condensers of the present day, with the exception of the modest "Abbe" Condenser of two simple uncorrected lenses, is that the Iris and the ring for dark ground-stops are placed too far from the back lens instead of being close to the anterior focal plane of the condenser. It is easily shown that such a remote Iris-opening or dark ground-stop produces decidedly oblique illumination of the extra-axial points of the object. With direct light this leads to an undesirable variation of the type of image and of resolving power in different parts of the field. With dark ground illumination the result is even more serious, for it is then necessary to use a far larger central stop to secure a dark background over the whole field than would suffice if the stop were placed close to the anterior focal plane of the condenser: such an unnecessarily large stop is highly objectionable, because it reduces the visibility of the coarser structures in the object.

The increasingly bad position of the iris in the condensers of higher power and shorter focal length supplies practically the whole explanation of the universal experience that high-power condensers will not work satisfactorily with low power objectives, especially for dark ground illumination.

The great thickness of the mechanical stage in English stands of the highest quality is the chief *reason* why the iris and "turn-out-ring" of high-power condensers have to be mounted so far below the back lens and a profound modification of the design of the stage with a view to making the part projecting over the condenser as thin as possible therefore appears to be the most desirable improvement of microscope stands from the optical designer's point of view.

In concluding these remarks on the optical design of microscope lenses I wish to point out that the whole subject is adequately dealt with in my lectures and classes at the Imperial College, and that students attending these for two or three years will be turned into competent designers, provided that they have a liking and natural aptitude for applied mathematics, are good at numerical calculations, and of an inventive type of mind.

As regards the *actual making of microscope objectives*, it must be borne in mind that the excellence of a computed lens system may be completely swamped by comparatively slight imperfections of workmanship, and that high accuracy in this respect is therefore of the utmost importance. In lenses of high N.A. computation shows that a departure from the prescribed radii and thicknesses by a fraction of a thousandth of an inch may lead to a notable loss of perfection, and the polished surfaces must also be truly spherical within less than half a wave-length of light. These limits can be easily observed if modern methods of gauging and measuring are adopted, and if all surfaces are polished to accurately made and conscientiously used test-plates. In the later years of my connection with the optical industry quite large batches of lenses used to be made directly from purely theoretical calculations of objectives of new types without any preliminary trials and without any experimental changes in the finished objectives, 95 or more per cent. of which would be found satisfactory in all respects just as they came

from the mounters' lathes. The tools and methods employed in really *manufacturing* lenses on this system were shown by Messrs. W. Watson and Sons, Ltd., at the exhibition at King's College in January, 1917, and will be found described and illustrated in the record of that exhibition.

In old English practice the component lenses of microscope objectives and condensers used to be fixed in their cells by cement of the sealing-wax type. Many old lenses which are still found in perfect adjustment 50 or more years after being mounted demonstrate that the cement may hold the lenses in correct position almost indefinitely: but other experiences, especially with lenses used in tropical countries, suggest that shifting may occur, and it is therefore to be strongly urged that all microscope lenses should be held between metallic shoulders at both ends by being bezelled into their cells, care being naturally required to avoid pressure and distortion through too tight a fit.

A few words may usefully be addressed to the users of microscope objectives. All the higher powers are very sensitive (the more so the more perfect the spherical correction) to the thickness of the coverglass *plus any mounting medium* intervening between object and coverglass, and also to variations of tube-length, and the best result can only be obtained by adapting the tube-length (or the adjustment of the correction-collar if there is one) to the individual coverglass. It is grossly unfair to interchange one objective with another of similar power but different make on the tube-length suiting the objective treated as the standard and then to condemn the new objective (usually an English one!) because it gives an obviously inferior image. It is not even fair merely to find the best tube-length for the new objective, for if the change of tube-length is considerable and in the direction of lengthening, the total magnification will be much higher and the image correspondingly duller and more fuzzy. To make the comparison fair, each objective should be tried at its own best tube-length, and with such an eye-piece as to give practically the same total magnification.

Another point on which users of objectives err to their own detriment is an excess of faith in numerical aperture. I have heard microscopists boast of possessing an objective, say, of 1.43 N.A., whereas somebody else had one of only barely 1.40, and a careful test would show that whilst the 1.43 was an indifferent lens, the 1.40 was excellent. The fancied advantage of 2 per cent., then, is really a disadvantage of perhaps 25 per cent. or more.

One of the few disservices which Abbe did to microscopy was the pushing of the N.A. of dry lenses to .95 and to a lesser extent the increase of that of oil-lenses to 1.40. The extreme marginal zone of the apochromatic dry objectives of .95 N.A. is particularly badly corrected, so much so that the lenses will only bear a solid illuminating cone of about .65 N.A. even on the Abbe test-plate, and that with annular light bringing only the marginal zone into action correction-collar and tube-length combined do not allow of reaching a point of good spherical correction. There is no doubt that Abbe's own earlier dictum still holds, to the effect that beyond about .85 N.A. the higher aberrations become unmanageable unless the free working distance is reduced to a very few thousandths of an inch.

A carefully computed objective of .85 N.A. will bear a full illuminating cone on suitable objects, and can thus realise its fullest resolving power. An objective of .95 with a condenser of .65 has the resolving power of the mean, or of .80 N.A., and is thus actually inferior except for freak resolutions with extremely oblique light. Oil objectives over 1.30 or at most 1.35 N.A. are also of very doubtful added value.

In closing this section I will once more quote without comment an anecdote of Fraunhofer, who received a complaint that a telescope supplied by him, although giving magnificent images, displayed certain fine scratches when examined with a magnifying glass! The reply sent by Fraunhofer is reported to have been:

"We have constructed the telescope to be looked through, not to be looked at."

A few sentences may perhaps be added as to the prospects for further improvements of microscopic performances. I have already stated in the first section that there is a bright ray of hope with regard to diminishing the curvature of field without loss of definition.

Advances in numerical aperture offer very little attraction. Abbe, in my opinion, carried the N.A. too far rather than not far enough, and I am not aware that any notable discovery has been achieved with the few monobromide-immersion objectives of N.A. 1.60 which he designed.

The use of shorter wave-length, *i.e.*, ultra-violet light, is a little more promising. There would be none but technical difficulties in the construction of lenses suitable for this work. But as only very few microscopists would be likely to go to the trouble of working in invisible light and of passing through a long apprenticeship in mastering the difficulties, apparatus of this description would necessarily be extremely costly, as the whole expense of designing and of constructing special tools would fall on a small number of outfits, or possibly on only a single one. And there would still be the grave drawback that the vast majority of objects would be opaque to extreme ultra-violet rays, and would only yield black-and-white outline pictures.

The so-called ultra microscope does not represent any advance in *resolving* power at all, but most decidedly the reverse. It is highly valuable for the detection of very minute particles and of their movements, which it achieves simply by intense darkground illumination, but the structure of the particles remains unrevealed, and only that would amount to an advance in resolving power. The seeing of these minute particles is, in fact, of precisely the same kind as the seeing of stars subtending less than .001 second of arc at night with the naked eye, the resolving power of which is of the order of 60 seconds.

Professor Alfred W. Porter, D.Sc., F.R S., spoke on "The Resolving Power of Microscopes."

NOTES ON THE RESOLVING POWER OF MICROSCOPES.

By Alfred W. Porter, D.Sc., F.R.S.

The question of resolving power was first of all discussed in connection with telescopes; but the problem for microscopes is essentially identical with that for telescopes. The fact that telescopes of large aperture gave smaller star-images than those with small aperture was first demonstrated by W. Herschel (1805) and later by Foucault (1858). The explanation was given in terms of the wave theory of light by Fraunhofer (1823) and by Airy (1834). Owing to the wave structure of light, each image of a luminous point formed by a lens is found (both experimentally and by the wave theory as developed by Fresnel) to be a circular bright disc surrounded by dark and bright rings of intensity diminishing outwards. If there are two bright sources sufficiently close—two stars, for example—their individual discs may overlap; and for a certain degree of closeness the confusion is so considerable that it is impossible to detect the double nature of the source.

Some convention had to be adopted in specifying the limit at which separation between the discs can be appreciated. The convention actually adopted has been based on the fact that if the centre of the image of one star falls on the first dark ring of the other, then the brightest part of the combined image will be a figure-of-eight disc having a faint diminution of intensity at its middle, which reveals its composite character. Now the radius of the first dark ring (as calculated by Fraunhofer) is

$$\frac{1.22\ \lambda F}{B}$$

where B is the diameter of the object-glass and λ the wave-length of the light received. The angular separation of the stars when just resolved (according to the convention) is obtained (in radians) by dividing this by the focal length of the lens. The reciprocal of this is the angular resolving power. Practice has shown (Dawes; E. M. Nelson) that resolution is obtained when the sources are more than 25 per cent. closer than this. It was shown theoretically by A. W. Porter (R. Micr. J., 1908, Part I.) that the true limit (for which there would be no diminution in intensity at the middle of the double image) corresponds to a closeness of the stars for which the intensity curves would cross at their points of inflexion; this limit corresponds very nearly to that obtained from observation.

The question of resolving power is not, however, an exact branch of science. It is the "thing seen" with which we are concerned, and this depends upon who sees. The human element enters; and

in consequence no exact statements can be made All we can get is rough estimations by which the quality of optical instruments can be compared. The conventional limit probably supplies this desideratum as well as any other, and since it possesses greater convenience, it may continue to be adopted, except, perhaps, in special problems.

The problem of the microscope has been studied specifically by Helmholtz (1874), Abbe (1873), and by the late Lord Rayleigh. The name of the late Lord Rayleigh may be repeated, because he has dealt with the whole problem in all its ramifications in a way which no other investigator has done. In particular may be mentioned the following papers by him: "On the Diffraction of Object-glasses," Coll. Papers, Vol. I., 163 (1872), "Investigations in Optics," I., 415 (1879-1880), "Resolving Power of Telescopes," I., 488 (1880), "Wave Theory Light," III., 47-187 (1888), "The Theory of Optical Images, with special reference to the Microscope," IV., 235 (1896), Ditto (supplementary paper), V., 118 (1903).

The microscope problem possesses several peculiarities which are not met with in stellar observation. In the first place the object is never self-luminous like a star, and much depends upon the character of the light transmitted through the object when it is semi-transparent or reflected from it when it is opaque. Again, the object seldom consists of points (which would be imaged as diffraction discs and rings), but may be isolated or series lines or may be of any other shape; and in each case may be either bright or dark compared with the "background"; each case requires specific consideration. No one has worked these cases out in full except Lord Rayleigh, and reference must be made to his papers cited above for the full investigations. We can deal here only with some general considerations.

In the first place the essential difference in detail between a telescope and microscope arises from the object being near the objective. It becomes convenient to refer to the semi-*angle* that the objective subtends at the object and the distance, e (instead of the angle) between the two sources which are here separated.

Now for two independent points the distance e for which resolution will occur is for a rectangular opening

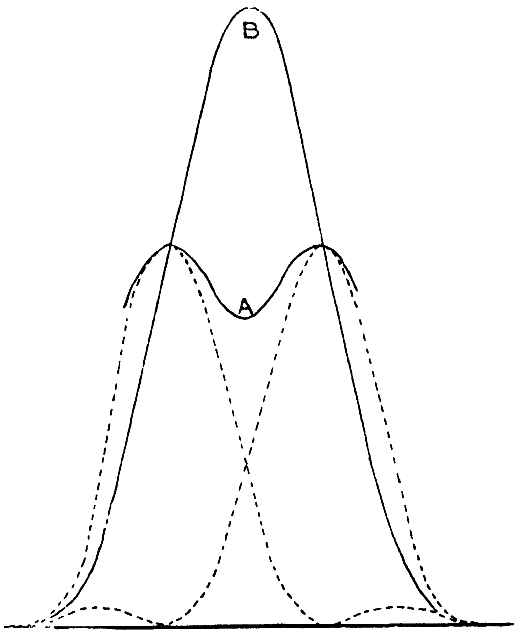
$$e = \frac{\lambda}{2\ n \sin a}$$

where n is the refractive index between the object and objective and λ is the wave-length of the light employed. On the other hand, Abbe, by considering a series of linear openings as object, found if the phase of the light passing through each opening is the same for all

$$e = \frac{\lambda}{n \sin a};$$

which is twice as great as before. The quantity n sin a he called the Numerical Aperture, and the reciprocal of *e* the resolving-power. These two examples bring out a necessary condition for securing fine resolution. The value of e is half as great as when the lights from different points of the object are independent, as when they are isophasal. Now this independence can be fairly secured by focussing a source of light by means of a condenser upon the

object. The condenser itself is an optical instrument to which the principles of resolution apply. The greater the Numerical Aperture (N.A.) of the condenser, the more nearly will each point of the object be seen by light from a distinct point of the source; but perfect independence is never secured. On the other hand, if no condenser is used, or if it be not focussed for the object, each point of the source will send light practically in one phase to a large patch of the object. Other points will do the same. Thus the independence between the lights at different points of the object breaks down, and Abbe's result will be approximated to. That is, for a dry objective ($n = 1$), instead of being able to resolve lines separated by $\lambda/2$ if $\sin \alpha = 1$, their distance apart will require to be at least λ. It is this halving of resolving power which is brought about by replacing proper by random illumination.



The difference between these two cases may to some appear obscure. It depends on the fact that the light which passes through neighbouring openings in the object spreads out by diffraction and the diffracted beams overlap in the field of view. If there is no definite phase relationship between these beams the case is analogous to that of illumination by two candles—the *intensities* of light can then be simply added together. When there is a phrase relationship this is not the case. At points where there is an opposition in phase the resultant amplitude may be zero. At intermediate points the phase difference may be zero or a whole number of periods. In this case the resultant *amplitude* is the sum of the separate amplitudes and the intensity is the square of the amplitude. For the sake of illustration two such superposed illuminations are shown in the figure. The dotted curve represents the components placed so that the maximum of one occurs at zero of the other. The

curve A is the resultant when the separate illuminations are independent, while B is the resultant when they are taken to be in the same phase. From A it might be inferred that the object was double from the presence of the two maxima in the resultant curve; in B the two maxima have merged into one and the resolution has vanished.

Examining, then, the case of two bright lines as the standard, it is seen that for a dry objective they must not be closer than half a wave-length for resolution under the best conditions of illumination. For the middle of the visible spectrum this means e = .000025 cms. For an immersion objective with immersion medium of refractive index n this should be divided by n. For light of shorter wave-lengths, e is proportionately less. Since this value is calculated (for simplicity) from the assumption that the lens aperture is rectangular, instead of circular, it differs very little from the limit given by the modified definition given by me and quoted near the beginning of this paper.

Magnification.

When an image is resolved it does not follow that it will be *seen* to be resolved. The division marks on a scale may be perfectly separate lines (much more so, in fact, than most optical images); yet they will not be seen separate if placed too far from the eye. It was stated by Helmholtz that they must subtend an angle between one and two minutes of arc in order to be seen as separate lines. In my own case and in those of about ten others recently tested the separation begins at about two minutes, *i.e.*, at shortest distance of clear vision, V, the lines must be separated about $\frac{V}{1800}$. This statement, of course, assumes that the eye can focus the lines in the position at which they are placed either without artificial aid or with the appropriate spectacles. It is also assumed that the illumination is good reading light. If the two lines in the image just resolved by a microscope objective subtend less angle than this, they will not be *seen* resolved. We can calculate, therefore, the limiting magnification necessary. An approximate calculation is sufficient.

With a total magnification of M_1M_2 the size of the image formed by the eye-piece is

$$M_1M_2\frac{\lambda}{2}.$$

It is this that must be $\frac{V}{1800}$.

Hence limiting magnification is $\frac{V}{1800}\cdot\frac{2}{\lambda}$

$$\doteq\frac{25 \text{ cms}}{900\times5.0\times10^{-5}\text{cms}}$$

$$=\frac{10^4}{18}.=555 \text{ nearly.}$$

This is the least total magnification necessary to reveal the structure in the case of this very successful resolution with a dry objective (N.A. = 1); and it is important to observe that it will only just reveal it. Now to see scale divisions well we do not place the scale so that they are only just separable. Even double the angular limit is advisable—and in some cases more. We may safely then take more like 1,000 magnifications for N.A. = 1, and up to 1,500 for N.A. = 1.5. This is precisely one of those data that cannot be definitely stated. We may, in fact, use 10 times the above minimum magnification in certain cases with advantage. But attention must be paid to one consideration in regard to which the graduated scale analogy is misleading. We bring a scale nearer not only to see the graduations easily, but to estimate small fractions of a division correctly. This presupposes that the marks are very fine—much finer than the interval between them. Now, in the image of an object whose structure is comparable with $e = \lambda/2$ there may be detail, but this detail is quite unlike the object. The artificial detail may be made clearer by extra magnification; but if the purpose of the observer is to find what the object is like, and not that of an investigator of the *errors* of optical images, the revelation of this artificial detail is useless and misleading. The only justification for excessive enlargement is when the image is thrown on a screen for inspection by a class, or similarly when a photographic print is made for the same purpose. In these cases it is intended to be observed from a distance; and the useful magnification is then such as will enable the true detail to be seen while the finer false detail will be blurred and inconspicuous. We must, therefore, distinguish between useful and useless magnification. It ought to be observed that it does not matter so far as this question is concerned whether the magnification is chiefly or *entirely* due to the objective. The eye-piece may be dispensed with, as is sometimes done in photomicrography; the calculation will not need any change.

This question should also be looked at from another standpoint. The eye-piece forms an image of the back lens of the objective outside itself; this is the "bright spot," or Ramsden circle. The rays that go through the bright spot are all those which penetrate the objective and are not stopped. The diameter of this spot is approximately $\frac{f}{T} \times$ diam. of back lens of objective, where T is the tube length and f the focal length of the eye-piece. Now in telescopes this can be larger than that of the normal eye-pupil with low powers, and in such a case only a part of the diameter of the object-glass is used. This can only happen with very low powers in microscopy. But with high powers (f small) the bright spot is very small, so that only a part of the pupil is effective. Now Helmholtz concluded that the normal eye-pupil will not bear much reduction without the image seen deteriorating, owing to imperfections in the eye. This point is not easy to demonstrate, because reduction in the aperture of the eye at first improves definition, since the eye is by no means free from aberrations. In my own case a fine line begins to be impaired when the pupil is limited to 2 mm. diameter by an artificial diaphragm. The decrease in sharpness

proceeds only slowly at first, as the diaphragm is further reduced, and it is not until about one millimetre diameter that very considerable deterioration is noticed. The eye is itself an optical instrument. The radius on the retina of the first dark ring of a point source is about 0.01 mm. when the diameter of the effective pupil is 1 mm. This is about eight times the diameter of a retinal cone. But the total magnification

$$M = M_1 M_2 = \frac{T}{F} \cdot \frac{V}{f} \text{ nearly}$$

$$= \frac{V}{F} \cdot \frac{\text{diam. back lens of obj.}}{\text{diam. bright spot}};$$

or taking V = 25 cms. and 2 mm. as the diameter of the bright spot, the magnification becomes

$$M = 125 \frac{\text{diam. back lens objective}}{F}.$$

For the case F = 0.2 cms., back lens = 0.6 cms. diam.

M = 375 diameters.

If we suppose a reduction of the bright spot to 0.1 cm. diam. to be permissible M = 750 diameters.

These results are of the same order as before.

In the case of photomicrography, as we have seen, the permissible magnification is the same whether an eye-piece is used or not. There is the added advantage that the photographic image can be examined *with the eye at best aperture.* On the other hand, there is deterioration in the image due to the grain in the plate, by an amount varying much for different plates. Where the finest representation is required, it should not be forgotten that the old " wet " process could be resorted to; or, failing that, process plates are the next best.

The attainment of as close an approach as possible to perfect images is limited by the extent of the elimination of all the aberrations calculated by methods of geometrical optics. Professor A. E. Conrady emphasises the fact that extension of numerical aperture has surpassed the value warranted by the existing design and construction of lenses. The same may be said concerning condensers even more emphatically. Pioneer investigations on waves of non-spherical form were made by Lord Rayleigh and others. The variation of the intensity in the focal plane of a planoconvex lens has been worked out by L. Silberstein (Phil. Mag., Jan., 1918), who at the same time exhibits the general method by which all such problems can be attacked; and the same kind of question has been worked out by graphical integration by Professor A. E. Conrady (Monthly Not., R. Astr. Soc., June, 1919). Not only are the aberrations of the " lenses " important. The performance of a condenser is modified by the presence of a slide of very imperfect optical quality. So far as its inequalities in thickness are concerned, the errors arising are much reduced by the immersion medium when used with the condenser; a similar remark holds in regard to the objective and cover glass.

With biological specimens the objective " focusses " only a thin layer. If this is near the top of the specimen, the light from the condenser is scattered by the layers beneath; if it is near the bottom

then the same applies to the emergent light. In either case there must be diminution of resolution. In the case of metallurgical specimens these defects are absent. The light is reflected from almost a mathematical surface. It may easily be, therefore, that for such specimens fullest advantage may be taken of permissible magnifying power, especially where the detail is of a simple character. This is seen, for example, in Figure 23 of the contribution by Sir R. Hadfield and Mr. Elliot, where the line markings of Pearlite are very clearly portrayed. On the other hand, in Figures 24 and 25, where there is evidently much fine detail below the resolution limit, it is not clear that the high magnification used is any advantage. Even if this fine detail appeared sharp, it would have no significance.

In the metallurgical case it must be borne in mind that if the mirror or prism in the vertical illuminator is opaque, it blocks out part of the aperture. The resolution of lines (such as those of pearlite) will be different, according to the azimuth in which they lie. Taking the aperture as semi-circular, the character of the image of a point is a central *oval* (instead of circle), the minor axis of the oval being parallel to the bounding diameter of the opening, and about half the length of the major axis (Struve, Mém. de l'Acad. des Sc. de St. Petersburg (7), XXX., No. 8 (1882); Bruns, Astr. Nachr., CIV., 1 (1883); Straubel, Inaug. Disért., Jena (1888); Scheiner and Hirayama, Abhand. Gesell., Berlin (1894), P. F. Everitt, R. Soc. Proc., A83, 302 (1910). Scheiner gives a photograph of the diffraction figure. Everitt gives also a diagram of lines of constant intensity).

Ultramicroscopy.

The considerations of this paper give no indication of the visibility of isolated particles, but only of the possibility of detecting their shape. If each gives sufficient light (either by self-luminosity, as in the case of stars, or by illumination by a powerful beam athwart the line of vision, as in ultramicroscopy), it will be seen. The amount of light it scatters is proportional to the *sixth* power of its radius when it is small compared with the wave-length. Its image is almost independent of its shape under the same condition. Under strong illumination larger particles ($<\lambda$) give complicated diffraction figures; but not much can be learned from attempts to interpret them. The visible disc is certainly much larger than the geometrical image of the particle. Similarly, a luminous line gives an image much wider than its geometric image. This case and that of an isolated dark line of finite width on a bright background have been worked out by Lord Rayleigh. In the latter case, when the background consists of light all in one phase, he concludes that the bar might well remain visible when the width of the bar is only one thirty-second part of the minimum distance between two lines for resolution. The slightly darkened image of the bar has then a width equal to about sixteen times that of its geometrical image and its apparent width is therefore quite illusory. In the case of a self-luminous background (*i.e.*, with phases completely independent), a bar of the same width has only half the visibility of the previous case, but it should be easily recognisable when its

width is one-third of the minimum interval for resolution. He cites the following simple experiment: "In front of the naked eye was held a piece of copper foil perforated by a fine needle hole. Observed through this, the structure of some gauze just disappeared *at a distance from the eye equal to 17 inches, the gauze containing* 46 meshes to the inch. On the other hand, a single wire .034 inches in diameter remained fairly visible up to a distance of 20 feet or 240 inches. The ratio between the angles subtended by the periodic structure of the gauze and the diameter of the wire was thus

$$\frac{.022}{.034}\times\frac{240}{17}=9.1."$$

He finds for the proportionate loss of illumination at the centre of the wire in this case

$$\frac{I-I_0}{I_0}=0.11$$

about what might have been expected.

The moral of these results is the recommendation of caution in interpreting even the width of the bars causing the streaking in microphotographs of pearlite, etc.

Besides the references in the text, the following may be given.

Airy, Tracts, 4th edit., p. 316 (reprinted as "Undulatory Theory of Optics"); Astr. Monthly Notices, XXXIII., 1872; Camb. Phil. Trans., 1834.

Foucault, Ann. de l'Observ. de Paris, t.v., 1858.

Verdet, Leçons d'Optique, t.I, p. 265.

Dawes, Mem. Astron. Soc., XXXV.

Ch. André, Etude de la Diffraction dans les Instruments d'Optique, Ann. de l'Ecole Norm., 1876.

U. Behn, u. W. Heuse, Zur demonstrations der Abbeschen Theorie des Mikroskops, Ber. d. deutsch Physik Ges. 4, 1906, Physik Z. Schr. 7, 750, 1906.

Dr. R. Mullineux Walmsley, Chairman of the Technical Optics Committee of the British Science Guild, outlined the work of that Committee.

I shall not detain you more than a few minutes. I attend this afternoon, as you know, as representative of the British Science Guild, and I thank the President for his kind reference in his Address to that Guild. The Symposium, I take it, and I hope we all take it, will be an epoch marking symposium in the development of the microscope. If it be not that, I very much fear that all the labour which you, Sir, have put so fully into the organisation of this Symposium will not have answered its full object. That being so, however, I think it is only right to the Guild that I should give just the bare facts of its connection with the development of the microscope in order that they may be placed on record in the Minutes.

It was on 14th May, 1915, that the British Science Guild called a Conference of manufacturers and users of microscopes to ascertain what was necessary to secure to the British Empire, and particularly to the British Isles, the trade in these valuable instruments, a large part of which for so long a period had gone to other lands. Great Britain is historically and in many ways the home of the microscope. The Conference met. It was attended by representatives of the leading makers of microscopes in England and by representatives of Government Departments, including the War Office, the Admiralty, the Colonial Office, and the India Office, and by certain well-known private users of microscopes. The necessity for standardisation was the first point discussed, and was very generally recognised; I think there was not a single dissentient. Details were asked for, and a Committee was appointed, which met quite quickly, and elected for its Chairman Sir Ronald Ross, one of the most distinguished users of the microscope that we have. The Committee did not lose much time. The Conference was held in May, the Long Vacation intervened, but the Committee reported in October, 1915. It published, for further discussion, its draft specifications of three types of microscope, one for general use, and not very expensive; another type for advanced pathological work, and a third type for research work. It is not, perhaps, surprising that with a distinguished medical man at its head, the Committee had devoted special attention to pathological work.

These specifications were published, and criticisms came in. It was pointed out that they did not cover the whole ground, and therefore the Guild appointed another Committee to consider what other microscopes should be submitted to standardisation by definite official specifications. A Committee for Microscopes for Special Purposes was appointed, of which I have the honour to be the Chairman. This Committee was appointed in the late part of 1915, and it reported during 1916. The original Committee had confined its recommendations in regard to pathological work to expensive micro-

scopes for advanced and research work. The new Committee, assisted, as was its predecessor, by manufacturers and distinguished users of the microscope—and for their assistance at both Committees the Guild is very grateful indeed—produced a specification for a student's petrological microscope, another one for general use in chemical laboratories, the cost of which was not to exceed £3 at pre-war prices: and, finally, a microscope for metallurgical work, in connection with which it had the assistance of distinguished metallurgists. These specifications were published during 1916 and circulated, but the trade determined that during the continuance of the war nothing could be done in the direction of standardisation until more quiet times came. The interval was not altogether lost, for these draft specifications were subject to criticism, and amended specifications, embodying considered modifications, have been drawn up, which we hope will be satisfactory to the trade and to users. The specifications will be published shortly.

A group of papers on aspects of the manufacture of the microscope was then read by **Mr. Conrad Beck, Mr. F. Watson Baker** and **Mr. Powell Swift,** and discussion on these papers ensued.

A STANDARD MICROSCOPE.

By Conrad Beck.

The British Science Guild having prepared a specification for a standard microscope, we have been engaged for a year in working out the manufacturing processes necessary to produce on a productive scale a microscope that should fulfil the requirements of this specification. The instrument has also certain additional new features which will be appreciated by microscopists.

The stand, limb and body are of a very solid, well-finished type, with the horseshoe base, jointed pillar and Jackson-shaped limb. The base and stage are both coated with a thick surface of ebonite, the body has a larger tube than is customary; the drawtube is graduated, and gives a mechanical tube length of from 140 to 200 millimetres. The standard length of 160 mm. has been adopted for which all object glasses are corrected. The thickness of cover glass for which dry object glasses are corrected is .15 mm., or .006 inch. All object glasses except the very lower power are of such lengths as to be in focus when used on a nose-piece or an objective changer. The fine adjustment is of entirely new design, the two milled heads, one on each side of the limb, are on the same axis, but each milled head actuates a different lever, and thus there are two different speeds, one of which is double as fine as the other, both of which are always in operation. The convenience of this is apparent to those who use object glasses of different powers. A fine adjustment that is sufficiently fine for delicate examinations with 1/12 object glass is frequently troublesome in focussing 1/6 inch.

The action of the slow motion is by a screw with a point impinging on a lever. This method has been considered, and in our opinion correctly so, the only known method of obtaining an absolutely free movement without sag or backlash.

The base of the microscope is provided with three rubber pads which remove vibration, but which can be detached if a rigid contact with the table is preferred.

The instrument is supplied in its simplest form with a plain tubular substage with an iris diaphragm, but this substage can be removed by the microscopist himself and replaced by any of the three more elaborate forms of substage, thus converting the instrument into a complete bacteriological or research instrument.

With the same end in view, a detachable mechanical stage can be attached at any time by the worker himself. All parts are made to standard gauges.

The base measures $6\frac{1}{2} \times 4 \times 1$ inch.

The distance of the stage from the table is $4\frac{3}{4}$ inches, which allows more room for substage apparatus than has been generally given.

The diameter of the mirrors is 2 inches, and they have a vertical adjustment of $1\frac{1}{2}$ inches.

The stage is 4 inches across, and there is a free distance of 3 inches between the optic axis and the limb.

The instrument will carry the ordinary double and triple nose-pieces, but we have taken up a new object glass changer invented by Mr. Sloan, of Birkenhead, which we have found by prolonged use to possess many advantages over a revolving nose-piece, and by putting down tools we have been able to produce it at a very moderate price. The design is so simple and rigid that almost absolute accuracy of centering can be permanently maintained, and the errors of mounting of individual object glasses can be compensated. There are no slides, but the adjustment throughout is made by screwed abutment pins with clamping screws. Once these are adjusted and fixed they cannot shift, and the utmost error we have been able to detect in the alignment of the optic axis by the tightness or looseness with which the clamp by which the object glass and its fitting is secured to the microscope is about 1/6 part of the field of 1/6.

We have introduced a new micrometer eye-piece and a new system of measurement which appears to be in advance of previous methods. The object glasses are all engraved with an initial magnifying power, which is the magnifying power at the first image formed by the object glass with a tube length of 160 mm. We have designed a new vernier scale for measuring objects, with a special positive eye-piece which is entirely above the scale, and when this is placed in the microscope the scale is in the exact position occupied by the image which is formed by the object glass when the medium power eye-piece is used. The object under examination is measured in 1/10 of a millimetre on this scale, and the result divided by the figure engraved on the object glass gives the actual size of the object. If a stage micrometer be placed under the microscope, the initial magnifying power of the object glass may be checked, though this will only be necessary for very exact work. If a Sloan object changer is used, the drawtube must be set to 150 mm., or if a nose-piece is used it must be set to 145 mm. to compensate for the increase in tube length produced by these pieces of apparatus.

At the conclusion of his paper **Mr. Conrad Beck** spoke on " Research in the Use of the Microscope."

RESEARCH IN THE USE OF THE MICROSCOPE.

By Conrad Beck.

In a series of lectures on the Theory of the Microscope which I delivered at the Society of Arts in the years 1907-8, I concluded with some remarks on the necessity for research on the use of the microscope. The methods upon which we now rely for the finest results obtained with high powers and for the best methods of illumination obtained with low and moderate powers are chiefly due to the work in the past of British amateur microscopists who have worked at the subject as a hobby and not as a profession. Now that the simpler problems have been solved, further improvements can only be looked for as the result of a combination of theory and practice which we can scarcely expect from any but trained research workers who can bring to the subject a combination of high optical knowledge and great skill in manipulation. Such work will, no doubt, require the co-operation of the manufacturer, but it is hopeless to expect that the manufacturer himself will have time to devote to the elucidation of the problems themselves. At the present time there are a large number of questions which will have to be solved before any very considerable progress is made in the science of microscopy.

In the lectures to which I refer I indicated, as an example of a possible direction for study, the ingenious suggestion of Mr. J. W. Gordon for reducing the size of the diffraction disc by the use of annular beams of light. This was only one point to illustrate the need of microscopical research. It is well understood that high power resolution depends on the aperture of the object glass, and yet in the new and extremely promising field of work opened up by dark ground illumination, we are deliberately reducing the aperture of our object glass to .9 or even .7 numerical aperture. There is no essential reason why an illuminator could not be devised by which much larger angles could be used in the object glass.

In the study of bacteria by dark ground illumination the diffraction images caused by the micro-organisms are extremely confusing, and there is room for research as to whether these images could not be profoundly modified by different methods of illumination, and to what extent the diffraction images indicate the structure of the organisms.

Another question, which, in my opinion, calls for serious research, is whether and to what extent a wide angle cone of light used in examining a histological specimen reveals or disguises structure, and to what extent the increase in brilliancy of illumination induced by opening up the aperture of the condenser increases or reduces the perfection of the image. I do not think there has been a satisfactory investigation on the examination of this class of

object with different apertures in the condenser when a proper compensating apparatus for keeping the intensity of the light the same with all apertures in the condenser is employed. Neither has there been sufficient attention paid to the question of increasing or reducing the brilliancy of the illumination without varying the aperture of the condenser.

In metallurgical work, the method of throwing the light through the object glass on to the object is undoubtedly very effective, but every convex surface that the light meets in passing through the object glass must of necessity throw back a proportion of the light, thus fogging the final image. There is room for research as to another means of illuminating the opaque objects to eliminate this element of flare and ghost images.

This short paper is written to indicate by a few suggestions that we are more likely to obtain real advances in microscopy by setting up researches on the use of the instrument than by devoting the whole of our time to the discussion of the mechanical details of a slow motion or the most convenient diameter of a milled head. I cannot believe that we are likely at the present time to find a body of disinterested amateurs, with the required scientific training, to take up these difficult subjects. The subjects I have mentioned do not begin to cover the field of research that is required, and if this meeting could be made instrumental in the inauguration of this class of research, it will have accomplished an extremely valuable piece of work.

PROGRESS OF MICROSCOPY FROM A MANUFACTURER'S POINT OF VIEW.

By F. Watson Baker.

The manufacturer, of necessity, is acquainted with the trend of microscopical development in every direction, for he is beset with suggestion and demand from workers throughout the world. The instruments he designs are largely moulded on his interpretation of such demands.

To a great extent there must be uniformity of design, but the expert, being usually a specialist, finds from experience that methods of work which he adopts as his own entail alterations of construction, and there is a tendency for such workers to attach importance to these details, and to recommend their incorporation in standard models.

It would be a matter of interest to see what the result would be if six independent leading workers were to prepare a specification of an ideal Microscope and Photomicrographic Camera.

English manufacturers have been in a position to meet the varied wishes of their patrons, because much of their work has been done by hand, and whereas with the machine-made microscope of the Continent and America the pattern has had to be taken as it stood, stipulations have invariably accompanied orders for all classes of English microscopes that certain features should be varied to suit the special views of those with whom the order rested.

Manufacturing in this manner has not tended to economic production, and, judging by the fact that it is possible to count all the manufacturers in Great Britain on the fingers of one hand at the present time, it will be fair to assume that such work is either unremunerative or involves difficulty or some disadvantage which discourages enterprise.

Past history reveals the fact that the development of the mechanical part of the microscope especially has been due to the British manufacturer, who has been largely directed and aided by notable progressive workers.

It is therefore not without interest to mention that thirty-eight years ago microscopes meeting fully to-day's needs, both in accuracy of working movements and stability of design, were made in this country.

When apochromatic objectives were first introduced, the only microscope stand on which they could be advantageously used was a British-made one. This alone had a fine adjustment worthy of its name and an efficient achromatic condenser.

Apochromatic substage condensers with means of centering them to the objective, the mechanical drawtube and the incorporated mechanical stage, together with the tripod form of foot, which alone gives stability in the instrument, were first made in this country.

The British maker has always excelled in microscopes of high class, involving skilled hand-work. No instruments in the world to-day vie with the beautiful hand-made first-class microscope stands which have emanated from British workshops.

There is no question that this procedure has been highly approved by expert workers, who found in the best English microscopes the power to use their optical systems with an exactness and variety of adjustment which is not supplied so completely in instruments of other countries.

Students' microscopes, made by the same methods with constant variation, could not compete with standard models made by machinery.

It became evident, therefore, to those who were anxious to establish the English microscope on a sound basis, that a definite model for a definite purpose must be made, and a specification for each type not subject to variation drawn up to the satisfaction of those who directed the purchase and use of microscopes, thus justifying manufacturers in putting down plant for their production in large quantities under economical conditions.

A Committee was accordingly formed by the British Science Guild, consisting of representatives of the many branches of Science and Industry and Government Departments for which microscopes were required, and eventually definite specifications for students, research and other instruments were prepared, which have received universal approval.

This was a great step in a forward direction for the optical manufacturers. Works and manufacturing facilities had grown very substantially during the war, but the hand-workers of the past had been greatly reduced by dispersal and death, and it was no longer possible to make microscopes in sufficient quantity in the customary manner of bygone days. They were therefore able to apply much of their plant and machinery to the production of machine-made microscopes for students' use while reserving for the few hand-workers available the refined special work of first-class instruments.

The amateur, who has not had his requirements satisfied for several years, is pressing for supplies of the best patterns of English microscopes, but the quantity demand comes from teaching institutions, and particularly from medical workers. Of these latter there are a larger number than in pre-war days, and it is believed that the machine-made microscopes on the specifications referred to will be found satisfactory.

On the optical side, the production of microscope objectives and achromatic condensers has been fraught with difficulty. Very little, if any, of the pre-war optical glass remained, and the nearest substitutes had to be used instead, until such time as the British glassmakers were able to give all the varieties that were required for the purpose. Honour is due to them for the success they have achieved in making nearly all the types of glass that have been called for.

Even for a fresh melting of the same glass it is generally necessary, on account of slight differences, to make changes in curves or distances of components, but when several glasses by a fresh

maker are dealt with, the sum of the differences in their constants, although the glasses are of the same *types*, necessitates the complete reconstruction of the objective. This is actually what is happening. It has only been during the last few months that the varieties of glass necessary have been delivered.

The computation of a high power objective usually occupies several weeks, and when this is done, proof plates and tools, which also require great care and a considerable amount of time in preparation, have to be made.

The full programme in this direction has not, therefore, been completed, but rapid progress is being made. The manufacturer is compelled to give priority to the production of objectives that are in most urgent demand, and those which by comparison are not so important will be made in full quantity as time progresses.

If the English microscope is to be firmly established, it requires now the whole-hearted support and recommendation of leaders in this country, and a generous patience while the preparation and supply of all that is needed is taking place.

The technical side of microscopy has, in this country, hitherto depended on two or three men whose names are well known. The means of education in practical optical science have been exceedingly limited hitherto, but it may be hoped that the instruction now being given in this subject will place at the disposal of the optical houses in the near future an increasing number of capable opticians. Such men must possess high technical and mathematical attainments, combined with practical knowledge which can only be obtained in the workshop.

There is one more point. The chief reason why the microscope is not manufactured by a larger number of firms in this country is, not merely on account of its technical difficulties, but because it is regarded as unremunerative. One large optical firm, at least, had microscopes in its post-war programme, but on studying the question, it was found to offer such small prospect of return for the effort and outlay that the project was abandoned, and financial men show no disposition to embark capital in a business of so highly technical a character. So it comes about that manufacturers are thrown very much on their own resources, and it is suggested that progress could be hastened and the whole business in microscope manufacture established in the fullest manner, so that it could stand four square to the competition of other countries, if capital were forthcoming on a generous scale for the purpose.

A NEW RESEARCH MICROSCOPE.

By Powell Swift.

We have, in connection with Messrs. R. & J. Beck, been in consultation with Sir Herbert Jackson and Mr. J. E. Barnard concerning the requirements of a better research microscope for all classes of exacting work than has hitherto been made. This consultation has proceeded only so far as to deal with certain important aspects of the case. We think the advances that are likely to be made in the microscope will be due to constant discussions between the users and the manufacturers of the instruments, and in order that the discussions which have up to the present taken place should be materialised into something definite, we have prepared a model embodying the points that have been so far settled and which should form a stepping stone towards further progress.

Whereas a standard microscope can be produced which may satisfy the requirements of the ordinary worker for a reasonably long period, we do not think that the best type of instrument is likely to remain stationary as long as scientific progress takes place.

Therefore, in putting before you this stand, although we think it marks a distinct improvement due to the helpful suggestions that we have already received, we must take entire responsibility ourselves for the details, and merely express our thanks for the valuable assistance we have received from Sir Herbert Jackson and Mr. J. E. Barnard, without its being supposed that they can be held responsible for an instrument which we have made in order to exhibit at this meeting, without having had time to discuss the final details with them.

The first point which was considered was rigidity, and, while adopting the general principle of our "Wales" model, with its curved limb and radial means of inclination, the casting had been made with a metal tie of great strength to connect the portion carrying the body with that carrying the stage, so that when moving from the vertical to the horizontal position there should be no alteration in focus, due to the slight torsion which is otherwise produced in the curved limb.

The body is 2 inches in diameter, so that a photographic lens placed in its interior enables a large field to be obtained and not cut off by the margin of the tube. A rack and pinion drawtube and supplementary sliding drawtube are provided, so that the mechanical tube length can be varied from 140 to 250 mm. The fine adjustment, which is of the twin side milled head type, is fitted with Messrs. Beck's new double lever adjustment, providing in this manner two very delicate adjustments, one of which is five times as fine as the other.

The entire stage is carried on a very massive right angle cradle, and racks up and down, with all its apparatus for metallurgical work having a travel of 2¾ inches. This is more solidly constructed than has been the case with such instruments, so that there shall be perfect rigidity.

The mechanical stage, which rotates concentrically, and is provided with centering screws for adjusting it to the optic axis, is a modification of that of our "Premier" model. The substage introduces an entirely new feature. It is provided with two cradles on the principle of the Sloan Objective Changer, introduced by Messrs. Beck, so that the whole of the substage apparatus, when mounted in interchangeable fittings with centering adjustments, can be instantly inserted in the substage, two pieces of apparatus being capable of insertion at one time. The body of the microscope is provided with a similar cradle, so that nose-pieces of a special character can instantly be interchanged if desired. For instance, the plain nose-piece may be replaced for petrological work with a nose-piece containing an analysing prism, Bertrand lens, quartz plate, etc., or with a nose-piece containing a high power vertical illuminator or other apparatus. The advantage of this system is applicable also to a great deal of physics research, as by introducing special apparatus into the substage or nose-piece, as occasion may require, a most perfect optical bench can be produced for general experimental work. There is a considerable class of delicate optical research which calls for an optical bench possessing the perfect adjustments of a microscope, and we believe that hitherto this requirement has not been met. By examination of the instrument it will be seen that almost any class of apparatus could be applied to the stand for making small and accurate measurements in physics, and although the chief object of this instrument is to provide the most perfect microscope that can be required, the other function for such an instrument has been borne in mind.

The base of the microscope is of the English tripod pattern, but has been provided with a new feature which is specially useful for photomicrography and optical bench work, which will also be appreciated by the ordinary observer. A hook shape casting is supplied which can be screwed down to the bench or camera, and an eccentric bar passing through the centre of the base will slide underneath this hook, when, by a slight motion of a lever at the side, the base of the microscope is locked firmly down in an exact position. Another lever between the uprights of the base clamps the joint by means of a right and left hand screw.

We have not alluded to the rack and pinion adjustments of the body, the stage, and the substage, which are of the usual spiral type, but might well call attention to the great width of the slides employed to give great stability to these adjustments.

It was decided in the consultations which took place towards the production of this microscope that while Messrs. Beck were employed on their standard instrument, we should undertake the manufacture of this special type, which would in all probability be sold by both the firms by which it is manufactured.

General Discussion.

The Chairman invited discussion on the group of papers just presented, and he called on Mr. Barnard to make an announcement.

Mr. J. E. Barnard: The point that I wish to raise will only take a few moments. It is this, that Messrs. Swift, I understand, have quite recently manufactured a series of apochromatic objectives. There is no particular innovation in that, because they have made them for years, but I believe that they admit that in some small particulars they come short of the German standard. They are so conscious of the superiority of these new objectives, however, that they are anxious that a Committee should decide as to whether these new objectives are the equals, and we sincerely hope we may say the superiors, of those of German manufacture. For this purpose, therefore, they have suggested, and after consulting with Sir Robert Hadfield we have agreed, that a Committee should be asked to adjudicate upon them, and therefore Sir Robert Hadfield, as President of the Faraday Society, the Presidents for the time being of the Royal Microscopical Society, the Optical Society, and the Photomicrographic Society, and perhaps such an eminent authority in the application of objectives to metallography as Sir George Beilby and one or two others, are to be asked to go into the question of the actual value of these objectives. I feel quite sure that that is a proposition that will appeal to the meeting for the part it will play, apart from any other question, in perpetuating the work of this Symposium. Therefore, even if the results arrived at are not all we hope, this Committee and its conclusions will form a very valuable connecting link between this Symposium and any succeeding work. I therefore have pleasure in moving that this Committee be authorised to proceed with this question.

Mr. F. Watson Baker (Messrs. W. Watson and Sons): May I enquire whether apochromatic objectives of other English firms can also be included? We have made apochromatic objectives for some years, and are quite willing to submit them.

Mr. Barnard: I should say there is no question about that. The reason I brought this up was that Messrs. Swift are the only ones who submitted objectives under the conditions set out, but if any other firm is in the position to submit some, the Committee will be only too anxious to consider them.

Dr. R. Mullineux Walmsley: I am most interested in this question from the educational side. One of the main questions before the Symposium is the production of microscopes in large quantities, and I venture to suggest that, as Mr. Watson Baker says at the end of his paper, the colleges concerned must give him the necessary

men for that work. I take that to be an absolute condition if we are to turn out instruments of high precision of this nature in quantity. The key of the situation lies in the inspection room of the factory, and unless the inspection room is adequately staffed with thoroughly trained men, the microscope manufacturers of this country cannot hope to rival what has been done—to which I refer with some diffidence in the presence of the President—in the engineering industry. Every engineer knows that the production of apparatus and machinery by the engineering industry—high-speed steam engines and things like that—has been due to efficient inspection by highly trained men in the inspection department. Parts are made in quantity, and are interchangeable, and the thing to aim at is to take the parts from store and have them fitted together without further adjustment by skilled workmen, and so to produce the finished article or machine. If the inspection department does its duty, we need not fear the competition of America or of France, both of which will be more serious than that of Germany in the near future, we need not fear it at all. The British microscope will then stand before the world and hold its own.

Lieut.-Colonel Gifford: In my experience I have worked out a good many apochromatic combinations, chiefly for telescopes, but I have never found any three glasses which gave a sufficiently long focus for microscopic objectives. That has led me to believe that the so-called apochromatic objectives for microscopes, excellent as they are, are not true apochromatics; I mean lenses which combine foci for three different portions of the spectrum. Whether that is so or not, I do not know, but I have met many people who know something of the subject who confirm me in this opinion.

Instructor-Commander M. A. Ainslie: This matter of the apochromatic objective has been occupying my attention for about 12 years, mainly from the point of view of what they would do in the resolution of very fine structure, and from the point of view of comparison between different types of objective. What put it into my mind to address the meeting was the fact that Mr. Swift just now was referring to his own objective. Mr. Swift a year or two ago was good enough to send me two 4 mm. objectives, one of which was entirely the equal of a perfect Zeiss 4 mm.; and I have some knowledge of Zeiss 4 mm. objectives, because I have used 18 of them on the same specimen, and I know that specimen by heart. One of the objectives sent me by Mr. Swift was fully equal to anything that Zeiss had done, but the other one was not. I presume that our English opticians are working, so to speak, to a standard. I know that they can turn out work which is in every way as good as anything that has ever been turned out in other countries; but while Continental opticians seem to have a habit of turning out what I might call objectives of 80 to 85 per cent. perfection, our English opticians seem sometimes to turn out something which is very fine—95 per cent.—but they often also turn out something which is about 60 per cent. perfection. In my experience in an amateur way, I have tested a very large number of immersion objectives, and of dry objectives with apertures from .4 to .95. I am

bound to say that the English and other opticians I have had the pleasure of dealing with have put these lenses at my disposal without stint, but I feel that we want to strike a far higher average of excellence. We do not want 95 per cent. perfection in 10 per cent. of the cases, and the remainder under 60 per cent. We want to strike a 90 per cent. average and depend upon it. I want to mention that point because of apochromatic objectives which I have seen made by English manufacturers. I can single out a 4 mm. of Mr. Swift's, a 4 mm. .85 aperture of Mr. Watson Baker, and a 2 mm. of Mr. Watson Baker. I cannot tell you much about the latter, because I do not know what became of the lens, but it was a very perfect one indeed. I can fully echo any remarks that have been made as to the high quality of possible work of English opticians, but I also should like to mention that I wish they would always do it.

Dr. E. C. Bousfield: The few remarks that I shall make to-night have been prompted by what has already fallen, especially from Mr. Barnard, with regard to apochromatic lenses. I think perhaps my experience of them is longer than that of anyone here, since, in conjunction with my friend, the late Mr. Lees Curties, whose loss so many of us deplore, the first photographs made in this country with Zeiss apochromatic lenses were made in my own house, on a dining-room table, incidentally with the tunnel built up with books between the microscope and the camera, and the result was perfectly satisfactory. I think success in this matter depends comparatively little upon the brasswork, but a great deal upon the glasswork, and almost most of all upon the operator. The apochromatic lenses which were at first supplied were of the finest possible quality. I think I have seen nothing better than the first 2 mm. apochromatic lens which I had from Zeiss, but, unfortunately, as was the case with all these early lenses, the glass was very soon attacked by the atmosphere, and in substituting a glass which was more resistent, the qualities of the lens suffered very considerably, and when it was returned to me the field was very much less flat than it had been in the first instance. There is one maker who has not been referred to to-night; but who was absolutely, I believe, the pioneer of apochromatic lens work in this country—I mean the firm of Powell and Leeland. Certainly they turned out—and I say it without any disrespect to anyone else—the very finest work in the shape of glass-work that has ever been used in the world, and British glass-work has been of remarkable excellence. They supplied me, for trial, with an apochromatic lens of their own manufacture, which was calculated in England and made in England, and it was absolutely perfect, but it had the same fault that the Zeiss lenses had, in being made of unstable glass. None of the 2 mm. lenses that I have seen made of the more resistent glass are at all free from roundness of field. I notice that in one of the papers that is to be laid before us reference is made to this roundness of field, and in actual working, those of us who have tried it with, say, 1,000 diameters, will agree that it is a very serious trouble indeed, and I do not see any way of getting over it. Lower magnification and a longer camera does not do so. I suppose the reasons are mathematical ones, which are beyond me.

I can only state the fact that if you get the same magnification with, say, a ½-inch lens and a long camera that you were getting with a ¼-inch lens and a short camera, you will hardly get more flatness of field in the one case than in the other.

There is just one other point, and that is that in all the photomicrographic apparatus which I have seen and possessed, there is one fault which seems to be inseparable from the instruments, and that is, with an extended camera, the connection between the operator and the focussing portion of the microscope, especially with lateral focussing milled-heads. These are extremely convenient, no doubt, for bench work in the laboratory, but for ordinary purposes of photomicrography it is extremely difficult to connect them satisfactorily with any form of extended focussing arrangement, and in any photomicrographic apparatus which may be put forward that point should certainly be kept in mind. The most efficient contrivance, I think, that I have ever seen—and the hint may be of use to some here, perhaps—was that of my friend, Dr. Neuhauss, of Berlin, who was well known as one of the very first photomicrographers in Germany. He simply carried a straight arm down from the axial focussing head of the fine adjustment, and attached a string to the lower end, with a weight on one side and a drum on the other, and so he managed to get his focussing fairly accurate. In conversation with Dr. Czapski once, when he came to see me, I pointed out to him that I found it impossible to get accurate focussing without tapping the bench, to make sure that the last adjustment was as delicate as possible, and he said, "Oh, that is quite the regular way for giving the final touch in delicate measurement"; so that I presume I had not gone very far wrong.

Lieut.-Colonel Gifford: I have in my possession two of these early Zeiss lenses. The late Mr. C. Lees Curties procured them for me at a very early period. One is marked No. 2, and is a 6 mm. of 0.95 N.A., and the other is a 3 mm. of 1.40 N.A., and is marked No. 34. Neither of them have suffered in the slightest, and I use them to-day as well as I did originally. On the other hand, I have Powell objectives. One of them is a 1/10 of 1.5 N.A.—a very large aperture indeed—and the other is 1/20 of the same N.A. The 1/10 became entirely obscured about two or three years ago. That, however, has been renovated by the present Mr. C. Lees Curties. The other one, the 1/20, has stood all through. At the same time, if you compare the two makers, I am afraid we must prefer the Zeiss. Both lenses which I possess of that make are simply perfect; I suppose they could not be quite perfect, but they are as perfect as they possibly can be. They stand any power you like to apply to them.

Dr. W. Rosenhain, F.R.S.: I want to draw attention to one particular point about the discussion which has impressed itself upon me in listening to it, and that is that there seem to be two totally distinct questions being discussed in a rather confused manner. The one is the question of establishing a commercial and industrial production of microscopes by mass production. This is, no doubt, a very excellent and valuable industrial step, with which, of course,

every sympathy, and I wish it every success, and shall be glad to do anything to assist it. That is one thing, but the progress of the microscope as an instrument of research and an instrument of precision is quite another thing, and we must not forget the one in view of the other. It was particularly gratifying to find that whilst two of our manufacturing friends were good enough to come here this evening and to speak almost entirely of mass production, the third gave us some prospect of work which was directed towards achieving the best possible that could be achieved, and I hope that it will not only receive the acknowledgment which I am sure it will deserve at the hands of all users of the microscope, but that all manufacturers will feel, I think I may say, that it is their duty, to look after that side of the thing, just as much as to send out a cheap microscope by the thousand; I hope they will succeed in both.

Mr. A. C. Banfield (*Communicated*).

War considerations and other matters have prevented any active participation on my part in things microscopical for the last five years, yet, once having used a microscope, it is impossible entirely to lose one's interest in this important aid to scientific research.

One of the main objects of this Symposium is to suggest possible means of improvement to this instrument, and I will confine my remarks entirely to certain points which have occurred to me at various times.

(1) It is the custom at present, in all high grade microscopes, to supply them with two slides, which carry respectively the coarse and fine adjustments. This is an expensive form of construction, and as I am one of those persons of opinion that very little is mechanically impossible, it should be possible to eliminate one of these slides, making the single slide do duty for both adjustments. Also, as constructed at present, the fine adjustment slide is nearest to the limb, thus causing the delicate micrometer screw or lever to carry the weight of the parts necessary to operate the coarse movement in addition to that of the body tube—the only part the fine adjustment should move.

(2) It is hard to explain the preference which undoubtedly exists in this country for the tripod foot, rightly termed the "English" foot, for it exists in no other country. Many English manufacturers enthuse on "the beautiful hand work" to be found in their instruments, and I imagine that the tripod foot is especially designed to show this off. Now the universal trend in all modern manufacturing is to eliminate entirely all possible hand work; nothing adds more to the total cost of any article than operations which have to be carried out entirely by hand. My indictment of the tripod foot is that it is of a shape which is difficult to cast, and impossible to machine. It is, furthermore, very bulky, and seriously interferes with the efficient operation of the sub-stage when the microscope is in a vertical position. A greater rigidity is claimed for this foot; this certainly is correct if one wants to lean on the instrument, otherwise there is no advantage over the horse-shoe foot, resting on its three milled pads.

(3) In most microscopes that I have used, the slides have been located in a position too near to the stage; the Continental makers are the worst sinners in this respect. The result of this practice is that when an object is focussed, the body tube has to be very considerably racked out, so that the slides only engage for about a third to half of their possible bearing. This does not add to the rigidity. The instrument should, of course, be designed in such a manner that with an objective in place on a changer, and focussed on an object, the male and female elements of the slide should be in complete engagement throughout their length.

(4) Even at the present state of mechanical advance, makers are still to be found preaching the virtues of the sprung slide. In the whole world of mechanics there is no more horrible device than this. It is supremely inaccurate and unreliable, and is merely adopted as an expedient to cover a state of residence in the dark ages of mechanics. Incidentally, I may remark, there seems a strange disinclination on the part of instrument makers to adopt modern manufacturing methods, the broaching machine, with the wonderful possibilities it holds out in the direction of dovetail and other slides, and eye-piece fittings appear to be quite unknown. Again, take such a simple job as a body tube. The common practice is to skim this in a bench lathe, then with the aid of a file and French cloth bring it to the lacquering stage—a tedious job, taking *quantum sufficit*, according to the workman. The whole job can be done on a modern grinder in a minute and a-half.

(5) Regarding the oblique illumination of metallographic specimens under high powers, it occurs to me that advantage may occur by reviving that old idea of fifty years ago in a modern form. If a glass rod, say a quarter of an inch in diameter and four inches long, is taken, and the ends squared and polished, it will serve to convey light from a source to an object with practically no loss. One end may almost touch an open arc, for instance, thus gathering rays at a high angle. These rays are carried along the rod by internal reflection (there is no need to silver the rod externally), emerging at the far end in a beautifully diffused bunch. This is no novelty to most of you, but I suggest that a variation of this idea may be of use in metallography. Take a worked slip, like a small Lummer plate, say 4 mm. wide and ½ mm. thick. On one end balsam a hemi-cylindrical lens of 3 or 4 mm. radius. The other end can be introduced well under an immersion objective, not quite under but probably far enough. For this purpose, the slip would have to be silvered, except at the ends, otherwise the light would leave the slip at the first contact with the oil. At the other end, parallel rays are directed from some powerful source. I merely suggest this expedient for your consideration, as there appears to be a necessity for it at times.

(6) I have no practical acquaintance with metallography, but a specimen was sent to me a few days ago by a Sheffield firm. Now this specimen is distinctly spherical, and if specimens of this description are the rule and not the exception, I do not wonder that

complaints "that the objective has not a flat field" are so common. The objective is computed for a mathematically flat object; if the specimen deviates from a true plane, then definition is bound to suffer. I merely refer to this point because it suggested to me an idea which it may profit some capable mathematician to investigate, which, briefly, is this:—

It is just as easy to prepare a metal specimen, worked to a definite radius, as it is to work it to a plane. Unfortunately, I am not a mathematician, but I suggest that by adopting some small concave radius for a metal specimen, say 10 mm., it may be possible greatly to improve the metallographic objective. The improvement may possibly take the form of a greatly simplified construction, or it may prove a means of increasing the N.A. of a lens. Personally, were I capable of it, I should compute it first of all unachromatised for use with the well-known Mercury line 5461, a powerful source of monochromatic light easily isolated. It could, if it showed promise, be further computed (all fluorite construction) for the powerful ultra-violet radiation at 1851. This would bring the N.A. for a 2 mm. lens to somewhere about 3.5.

(7) I have suggested the above (under 6) as a possible source of an improved objective for metallurgical purposes, but by working a specimen to a radius, it is possible to compensate an apochromatic or other objective which lacks flatness of field, by applying the well-known sphereometer formula.

Take a ruled stage micrometer, focus the centre of the field, and note reading on micrometer drum of the fine adjustment, after which take the reading of the alteration necessary to render the lines at the edge of the field sharp. Then if S is the semi-diameter of the circle in the object plane represented by the field of view, we can immediately say that if the object be given a curvature whose radius is

$$R = \frac{S^2}{2d}$$

the field of view will be in focus simultaneously at the centre and margin. d is, of course, the difference between the two readings of the fine adjustment drum.

A further group of papers dealing with various general aspects of microscope design and construction, presented by **M. Eugene Schneider, Professor Alexander Silverman, Dr. R. E. Slade and Mr. G. I. Higson,** and **Mr. R. J. E. Hanson** were taken as read.

NOTES ON THE FUTURE OF THE MICROSCOPE.

By Eugene Schneider.

A. Mechanical Improvement.—It is very difficult to make precise suggestions as to mechanical improvement. The stands of the different constructors are approaching a type, which in a measure, tends to become classical. The initiative will in this development apparently have to be taken by the scientists and industrials. They will point out to the designers the defects of their instruments, and will indicate the modifications which technical progress requires. Yet we may specify one detail of improvement which might easily be realised. For a long time all designers have adopted the standard "universal screw" for the objectives. Nothing analogous has yet been done for the tubes in which slide the eye-pieces and condensers. This is frequently a matter of inconvenience to the microscopist, who possesses several instruments or who wishes to fit eye-pieces and condensers of different styles into his microscope and stand.

B. Optical Improvements. a. Eye-pieces.—As regards the optical parts, the microscopist, whatever his speciality, has all the necessary instruments at his disposal. At the outside, one might wish for eye-pieces of larger field for dissection or for the study of larger slides. That however, would necessitate a larger tube diameter. The field of the actual objectives is, moreover, of considerable curvature already, and one would gain little by trying to carry the observations to parts far away from the central portion.

b. Objectives.—Abbe has shown that the definition of the microscope is limited by diffraction effects, not on the edge of the objective, but on the object. He has established that the definition—which is frequently styled resolving power—is proportional to what he has termed "the numerical aperture," which he defined by the expression: numerical aperture = n sin u. There u is the semi-angular aperture, that is to say, half of the apex angle of the cone of rays passing through the object and admitted into the objective (Fig. 1), while n is the refractive index of the medium surrounding the front lens of the objective. More strictly expressed, n is the index of the least refractive substance which is found between the object and the second element of the front lens.

But n is a function of the wave-length. In order to increase the numerical aperture, and at the same time the theoretical range of definition, we may hence increase u, or increase n, or decrease λ

Dry Systems of Objectives.—The object itself is immersed in a medium of some refractive power, water, glycerin, Canada balsam, etc. But a cushion of air is always left between the cover-glass and the lens. As the refractive power of the air is taken as unit by opticians. the n in that cushion has the value 1, and hence the numerical aperature is equal sin u. In certain dry systems of apochromatic objectives, the numerical aperture attains the value 0.95.

which corresponds to an angular aperature of 144° (compare Fig. 2). To go further in this respect appears to be impossible. On the one hand the rays would no longer issue from the point lens; on the other hand, the most oblique rays like OI. (Fig. 2) would strike the first dioptric plane at almost grazing incidence, and the losses by reflection would become very considerable.

Immersion Objectives.—Keeping the angular value of the aperture constant, the immersion increases the magnitude of n (Fig. 3). Cedar wood oil (n=1.52) is mostly made use of; it is interposed between the glass cover and the front lens. The numerical aperture may be raised to 1.40. In the great majority of cases nothing will be gained by exceeding this limit. Medical men, botanists, histologists and bacteriologists study their specimens when immersed in water, glycerin, salt solutions and, more rarely, Canada balsam. Only in this last-mentioned case they really utilise the total numerical aperture of their objective. For instance, when the object is placed in water, with a numerical aperture of 1.40, we have numerical

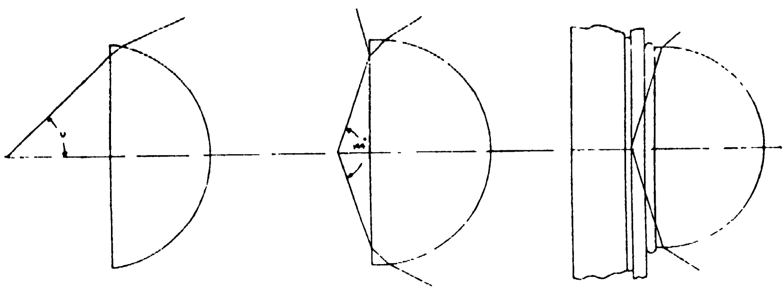


FIG. 1. FIG. 2. FIG. 3.

aperture utilised = 1.33/1.52 of total aperture = 1.22. The *conclusion* to be drawn is that, taking into consideration *only the theoretical definition* and the customary practice, one may say that the microscopic definition has already reached its limit. We have not referred to the variation of λ ; that point will be discussed when we pass to microphotography.

Special Cases. (*a*) *Diatoms.*—For diatoms and in general for very fine and refractory objects, we can make use of a medium and an immersion liquid of very high index. For the silica test of diatoms, *e.g.*, we can apply a solid medium of relatively high melting-point, as silica will stand high temperatures. In this way Zeiss has arrived at an objective of a numerical aperture of 1.60 in making use of a dense flint (for slip and cover) of monobromonaphthalene (immersion fluid), and a solution of arsenic sulphide in bromine (as medium). There again we seem to have reached the limit.

(*b*) *Metallography.*—In metallography the immersion liquid touches the object directly without interposition of any lamella. In this case there is no theoretical reason against the application of extreme numerical apertures; unfortunately the illumination problem becomes particularly difficult.

Aberrations.—To a certain numerical aperture corresponds a certain limit of definition. But this limit is not always attained; in most cases aberrations distort the image, and the microscope proves inferior to what one might hope for.

Spherical Aberration.—This aberration can, in general, fairly well be corrected for a given radiation. The properties of the aplanatic points in the front lens facilitate the task of the constructor in a singular measure. When we consider rays of one colour only, there is little more to be achieved from this point of view with well-constructed objectives.

Sine Condition.—This condition—which says that, central aberration having been corrected for, the point images outside the axis are exempt from coma—is equally satisfied in all good instruments.

Curvature of Field.—As regards flatness, everything, or nearly everything, remains to be done. The field of better-class objectives is curved to a deplorable degree, so that it is impossible to make a useful observation on the borders of the field when adjustment is made for the central portion. The manipulation of the micrometer screw no doubt admits of rapid focussing and facilitates the successive exploration of different portions of the field. Yet there remains a loss of time and a certain difficulty in steadying the ensemble. The defect becomes more pronounced in photomicrographic work, though it can be mitigated by the aid of a projection lens, suitably corrected But one must not indulge in illusions. As matters are and with the materials at the disposal of the optician, it is impossible to assert that we shall some day succeed in completely correcting for curvature of field.

Chromatism.—Chromatism is never eliminated, though it may be toned down. The so-called achromatic objectives, cut out of the customary glasses, always show more or less troublesome coloured fringes on the outlines of objects. Much has been written about the correction for n radiations by the aid of n glasses. When several conditions are written for achromatisation it can easily be recognised that the roots are real only for certain values of the co-efficients of partial dispersions of the glasses. In the very simple case of two glasses we may write: $\frac{\phi_1}{\nu_1} + \frac{\phi_2}{\nu_2} = 0$

or in another form $\frac{\phi_2}{\phi_1} = -\frac{\nu_2}{\nu_1}$

where ϕ_1 = the focal power of the convergent lens, ϕ_2 = the focal power of the divergent lens, ν_2 = the ratio of $(n_2 - 1)$ to the dispersion between the two radiations to be achromatised:

$$\nu_2 = \frac{n_2 - 1}{n_2'' - n_2'},\ \text{for the divergent lens,}$$

and ν_1 = the same ratio $\frac{n_1 - 1}{n_1'' - n_1''}$ for the convergent one. If we possessed pairs of materials such that the ratio were independent of the chosen interval, we might with two glasses achromatise all the radiations. The pupils of Abbe have worked out this problem. The Jena glassworks have produced materials which satisfy the condition defined above *imperfectly*, but *better than the usual glasses*. The term *apochromatic* has

been reserved for these instruments. Unfortunately the new flints, the telescope flint, boro-silicate flint, borate flint, etc., have small dispersive power. The lens curvatures have to be exaggerated, the zonal aberrations become disturbing, their correction is troublesome, the objectives are difficult to construct, and, in spite of their very real superiority over the ordinary achromatic objectives, the price of the apochromatc sometimes makes the buyer hesitate.

In our opinion, the progress of the microscope, as to *easy and compact correction of aberration, will depend much more upon the work of the glass-maker than upon the calculations of the optician.*

We can now form a clearer opinion concerning the interest which extreme magnifications of 5,000, 10,000 diameters and more can present. On Abbe's theory M. von Rohr has fixed the smallest distance that an objective of aperture 1.40 can resolve at 0.00015 mm. The eye can separate about 1 inch, say 0.1 at a distance of 33 mm. An enlargement of 700 diams. enables us to see all the details of an object. A more powerful eye-piece only enlarges the image without bringing out any further detail. The image which the observer examines may be less perfect than the normal view; on the other hand, the eye is fatigued by being strained to its maximum effort. For this reason, one has gone up to enlargements of 2,000 and 3,000 diameters. This latter magnification is excessive, however, and we have never seen it applied for any useful purpose in microscopy. In microphotography, on the other hand, it is sometimes serviceable to magnify 10,000 times and to use even higher powers—for instance, when the image is to be exhibited in the lecture theatre, or when one wishes to touch up a proof or to put references on it.

Photomicrography.—So far we have presumed working in ordinary light. As the photographic plate is sensitive to ultra-violet radiations, we can in photomicrography obtain higher definition by diminishing the λ. One difficulty creeps up at once, however: most of the optical materials are opaque to ultra-violet radiations. Rohr built up the whole optical system out of fused quartz; there was no correction for chromatism, and illumination was effected by one of the aluminium radiations. The index of quartz for D rays is $n = 1.54$; for the ray AI_{32}, the index rises to 1.69. The immersion liquid is glycerin; one is, in many cases, restricted by the opacity of the preparation itself. In these respects the limit seems to have already been attained, or nearly been attained.

Condensers.—As regards condensers, the constructors may be said to have preceded the microscopist. For delicate researches, non-corrected condensers are frequently used; yet they should be achromatic. The theory of Abbe assumes that the object is placed in the image of the luminous source. That is, with ordinary condensers, obviously possible only for one single radiation, and one point of the field. A bad illumination is so disastrous that, even at the present hour, many investigators are by no means convinced of the superiority of the apochromatic instrument. One cannot tell them often enough that this defect is solely due to the insufficiency of their condenser and to the poor choice of a luminous source. Achromatic, and even apochromatic condensers are in existence, and a *deplorable misjudgment* alone has prevented their general use.

Metallography.—In metallography the objective serves as condenser. The illumination thus obtained may be perfect (especially with apochromatics), but the lenses are more or less marked, which somewhat impairs their definition. In any case, it is the illumination which will have to be studied for improvements. The problem appears to be singularly arduous, and a long time will no doubt elapse before the introduction of notable perfections can be hoped for.

Conclusion.—In a general way mechanical perfections of the microscope will naturally result from progress in micrographic technics. From the optical point of view we are restricted, at least in usual practice, by the impossibility of going beyond the numerical aperture of 1.40. Better correction of the aberrations and especially of the field curvature seem only to be possible by the creation of new optical materials. Finally, the use of ultra-violet rays admits of increasing the definition to a considerable degree; but the insufficient transparency of the media frequently imposes a limit.

A NEW MICROSCOPE ILLUMINATOR.

By Alexander Silverman
(University of Pittsburgh, U.S.A.)

The device here described has already come into extensive use in the United States. The illuminator* and this paper are submitted for consideration by interested British societies.

The Lamp.—This consists of a quarter-inch glass tube containing a single tungsten filament. The tube is bent into a circle of one-inch inside diameter, and one and one-half inch outside diameter. It is made of colourless or blue (daylight) glass, and silvered, so that light is reflected downward from the circular source to the object being examined. The possibility of silvering the entire lamp and cutting a lateral line-slit in the mirror at the smallest diameter is under consideration to determine the possibility of producing through a plane of light a sort of ultra-microscope effect for the examination of bacteria.

The lamp is operated at 0.9 ampere and 13.5 volts for visual work, and 1.06 amperes and 18 volts for photographic work. Current from an ordinary lighting circuit is utilised, and controlled through a special rheostat (Fig. 1), which contains a push-button switch for the lower current and a spring-contact for the higher one.

The Holder.—An automatically adjustable support (Fig. 2), provided with three iris-like fingers, controlled by springs, is attached concentrically about the objective. The lamp is held to the underside of the support by two curved prongs and a perforated spring clip which slips over the exhaust protuberance of the lamp. The terminal wires from the lamp are attached to binding posts which are so constructed that they will also receive the brass pegs attached to the cord coming from the rheostat. These pegs may be inserted vertically or horizontally.

For general observation the lower portion of the lamp is in a plane with the flat face of the objective lens, but it may be raised or lowered to meet the needs of the operator.

Binocular Microscopes.—While the lamp-holder is clamped directly to the objective on monocular (Fig. 1), and single-objective binocular microscopes when 16 mm. or higher power objectives are employed, a stage support (Fig. 3) is provided for use with low power objectives and the Greenough binocular microscope. Lateral adjustment of the stage adapter centres the light and vertical

* U.S. Patents 1,311,185, 1,311,186 and 1,257,287, British Patent 125,187, Canadian Patent 185,283, Italian Patent 48/485, French Patent 489,304. Other foreign patents pending.

adjustment enables the operator to keep the lamp at a constant distance from the object under examination.

The Shutter.—A shutter, which slips inside the lamp circle, may be placed under the lamp to cut off the light from one-half of the circle, so as to produce oblique illumination where this is desirable. Where depth without shadows is desired the shutter is unnecessary.

The Absorption Disc.—This is a dull black disc for covering highly polished surfaces, so that only the small portion under examination is exposed to the light.

Photomicrography.—For photomicrographic work the illuminator is attached as already described, and the camera employed without lenses, except those contained in the objective and ocular. For work done in this laboratory the camera shutter was left wide open. 16 and 32 mm. objectives were employed with a 10× ocular. As most microscopes are now equipped with vertical illuminators, the tube of such microscopes should be extended about 16 mm. when the vertical illuminator is removed and the new one attached. It is also desirable to use a Davis shutter in conjunction with the objective. Hammer ortho extra rapid plates were exposed for from 10 to 40 seconds, depending on the nature of the object photographed.

Low Power Work.—Excellent results have been obtained with low power objectives from 60 mm. to 16 mm. By using the stage adapter for 32 mm. and less powerful objectives, it is possible to place the lamp about one-quarter of an inch from the object and obtain beautiful effects. This is of advantage also with the double objective binocular microscope.

High Power Work.—The illuminator has proven satisfactory for oil-immersion work with a 1.8 mm. objective and 15× ocular (1,425 diameters). The markings on diatoms and structure of fine-grained alloys show clearly.

Heat of the Lamp.—To allay any fear concerning the heat radiated or conducted from the lamp, the writer begs to state that in his laboratory the lamp was attached to various objectives and run continuously at 100 per cent. over-voltage for more than half an hour without doing any harm to the objectives. Dr. E. M. Chamot, of Cornell University, conducted an independent series of experiments in which he drilled a hole in the side of the objective, inserting a small pyrometer tube between the lenses. He burned the lamp continuously over long periods, and pronounced it harmless.

Advantages.—The new illuminator, when used for the examination of opaque objects and others which may be viewed by reflected light, shows a greater wealth of detail than is obtainable by older methods.

It is of special value for examining objects which possess light-absorbing surfaces, invisible under vertical light, which are beautiful under the new light. This is easily verified by viewing papers, textiles, leaf rusts, insect wings, potato mould, etc.

In metals and alloys it shows the depth of penetration of the etching medium, contrast, colour, and as Director Stratton, of the U.S. Bureau of Standards, has pointed out, it enables one to see the slag content of pits which appear black under vertical light.

The new illuminator may be used without removing the vertical illuminator. By switching the respective lights on in turn, valuable comparative studies may be made.

The illuminator, when attached to the objective or to a special arm of the stage adapter, may be lowered into hollow objects, such as the steel test dishes used in the enamel industry, or vessels used for the study of pond life, etc.

The illuminator is attached to the microscope, which may be moved without throwing the light out of adjustment. In photographing it vibrates with the microscope should the latter be jarred.

The new illuminator eliminates eye strain. The intensity of light which reaches the eye is lower than that produced by other methods. There is no polished disc to interfere with the vision, and only rays reflected by the object examined strike the retina.

Acknowledgments.—The writer desires to express his appreciation of the generous co-operation of microscopists who have experimented with the new device. He desires especially to thank your Mr. S. C. Akehurst for the pleasure of his company and valuable suggestions made during his visit to the States, and for his kindness in presenting this paper before the members of your society.

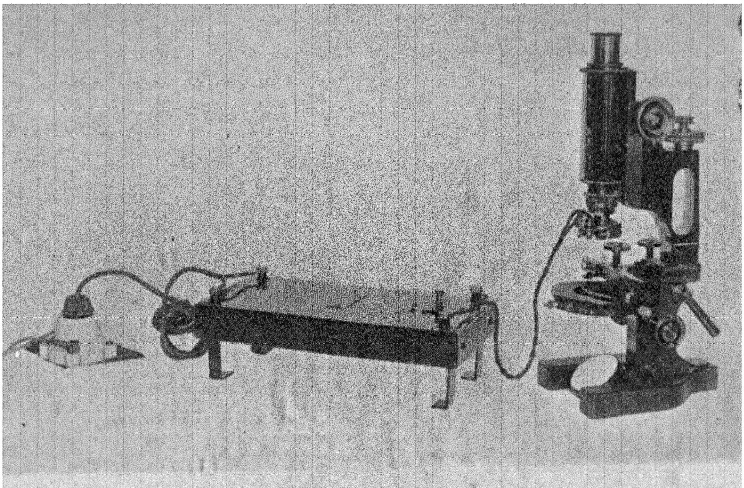


FIG 1.

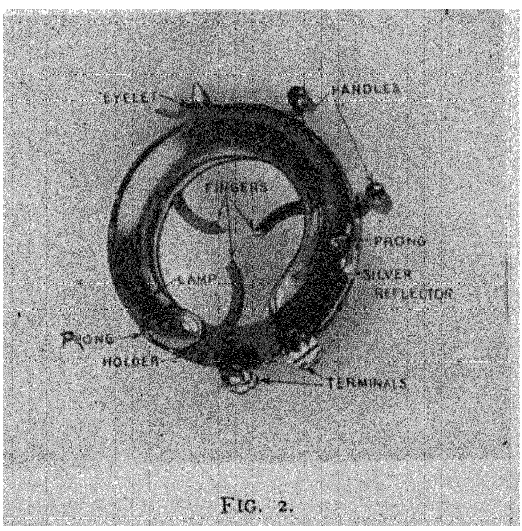

EYELET
HANDLES
FINGERS
PRONG
SILVER REFLECTOR
LAMP
PRONG
HOLDER
TERMINALS

FIG. 2.

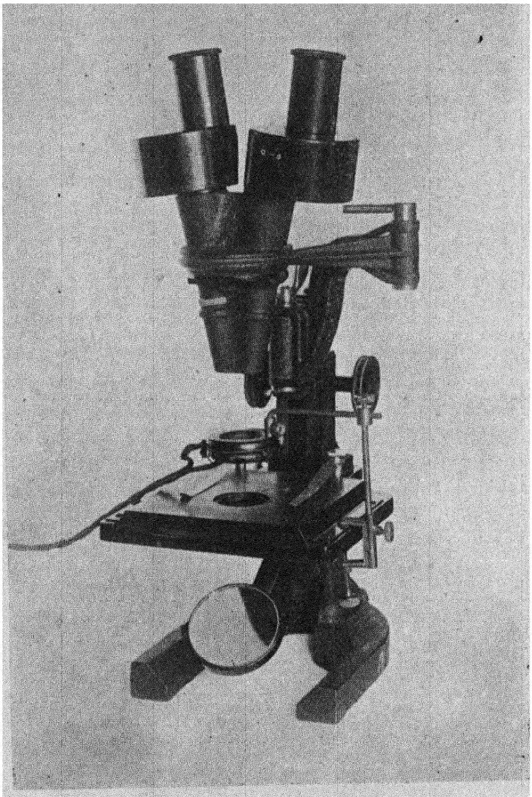


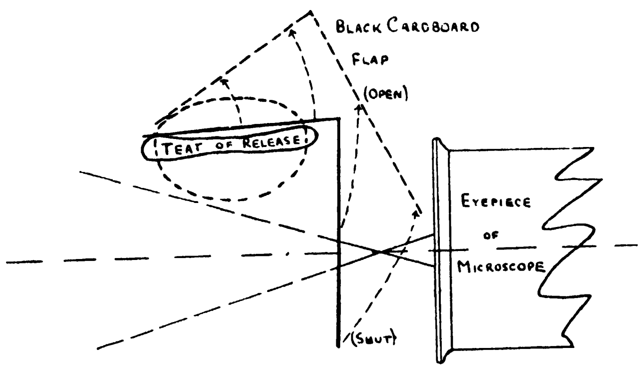
FIG. 3.

SOME PROBLEMS IN HIGH POWER PHOTOMICROGRAPHY.

By R. E. Slade, M.C., D.Sc., F.I.C., and G. I. Higson, M.Sc., A.I.C.

In an investigation of photographic emulsions we have found it necessary to take photomicrographs, using the greatest resolving power which we could obtain. In our attempts to overcome various difficulties inherent in different forms of apparatus, we have constructed an apparatus, which we believe contains some novel features.

The source of illumination is a 100 c.p. " Pointolite " lamp contained in a light tight box, a light tight connection being made between this box and the sub-stage condenser of the microscope, which is used in a horizontal position. Although this box is not ventilated we have not been troubled by heat from the lamp. No optical system or heat absorbing cell is interposed between the Pointolite lamp and the condenser, but an arrangement is fitted for introducing a colour screen in this position. The microscope is used with or without an eye-piece in



Action of Vibrationless Shutter

a room which is totally dark, and the image is projected on to the plate, placed in a holder about one foot from the microscope, no camera being used. The whole apparatus is mounted on a solid block of ash. Focussing is done direct on to a piece of white card placed in the plate holder, a shutter is then brought down just in front of the eye-piece of the microscope, a plate put into the plate holder, and the exposure made.

This shutter, which is mounted quite separately from the base of the apparatus, consists of a roller blind shutter release, to the teat of which is attached a flap of black card (see Fig.), which is lifted clear of the path of the light rays by pressing the bulb of the release, exposure thus being made with complete absence of vibration.

In order to surmount the difficulty of imperfect achromatisation of the lenses, a green filter is used and photographs are taken on process plates sensitive to this light. In all apochromatic lenses there is always a good deal of curvature of field, and we should like to suggest that for photomicrographic purposes it would be useful to have a lens without any colour correction, if the elimination of other forms of aberration and curvature of field would be thereby facilitated.

The illumination used is always what is usually termed critical, that is to say, the light source is in focus on the plate at the same time as the object being photographed, this being rendered possible by the uniformity of illumination over the whole of the light source. In this connection we should like to put forward a theory of the well-known phenomenon of the flooding of light over the image at critical illumination when the aperture of the condenser is fully open. We believe that the explanation of at any rate a part of this is that the image of the light source which lies in the plane of the object is not an infinitely thin plane, and there is so little depth of focus with a high power objective that we have the effect of the image of a bright surface lying just in front or just behind the object and out of focus on the plate, producing the so-called flooding effect. If we cut down the aperture of the condenser we eventually use only light which is almost parallel, and therefore obtain a shadow photograph which is absolutely free from flooding. If we cut down the aperture only a small amount we may do so sufficiently to make the effect of flooding negligible. In support of this we may mention that flooding is not obtained if the image of the light source is very much out of focus. In the " Pointolite " lamp the curvature of the light source will contribute to this effect.

In some of our earlier work we used an achromatic lens between the " Pointolite " lamp and the condenser, but it was the light source which was always brought to a focus on the screen, and not the image of a diaphragm over the lens, as is sometimes done. This lens was used to magnify the image of the light source so that a larger part of the object could be illuminated, but the same effect is now secured by bringing the lamp as close as possible to the condenser. In this way we can illuminate an area of the object, which is a little larger than the flat part of the microscopic field. This increases the ease of aligning the optical system, and moreover slightly increases the working distance of the condenser, which, however, is never much more than 1 mm.

The exposure with the orthochromatic process plates in use, with the green filter and a magnification up to 2,000 diameters, varies from 2 to 10 seconds. In this connection it is important to note that for all work requiring the greatest resolution process plates (i.e., plates with a hard working emulsion*) must be used. (Goldberg, P. J., 52, 302 (1912).)

Laboratory of the British Photographic Research Association,
Chemical Department,
University College,
Gower Street.

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* In the December number of the *Photographic Journal* we have shown what type of emulsion is required to make a good process plate.

FATIGUE FACTORS INCIDENTAL IN THE USE OF CERTAIN OPTICAL INSTRUMENTS.

By Surgeon-Commander R. J. E. Hanson, O.B.E., M.A. (Cantab.), R.N.V.R.

Fatigue—when it exceeds physiological limits—is one of the most potent drawbacks to industrial efficiency.

Moreover, it is usually of no sudden onset after commencing the use of optical instrument or projection apparatus, but is rather the result of summation of effect.

The causation of undue fatigue may be summarized under three headings:—

Section 1.—*Faulty environment.*

(A) Mal Hygiene of the home.

(B) Mal Hygiene of the workshop.

(In connection with "A," the influence of day and continuation school conditions to be reckoned with.

Section 2.—*Defects in the Eye.*

(A) Extrinsic, *e.g.*, Heterophoria.

(B) Intrinsic, *e.g.*, Ametropia, etc.

Section 3.—*Central and Psychological.*

(Or a combination of any, or all, the above.)

The illuminating engineer is at work to secure good lighting conditions, with beneficial results in many directions. Of great importance also are satisfactory conditions of ventilation, temperature and hygrometry.

In this short communiqué, I desire particularly to consider defects in, or misuse of, the muscular mechanism of eye movement, resulting in mal-orientation of the eyes, *i.e.*, Section 2 (A).

In the use of the bioscope one has opportunity to study the fatigue resulting from flicker; excessive contrast (defective retinal adaptation);* inadequate stimulation of the retinal periphery, and disproportion between dimensions and illumination of screen picture and the distance therefrom of the seat occupied by the observer.

The distance between audience and picture screen should not be less than 3 × D (D = diagonal measurement of the picture).

* The retinal periphery is best stimulated by means of clusters of frosted ruby (Fig. 1) coloured lamps suspended on brackets at intervals alongside the auditorium.

If an observer sits in the " auditorium " *below* the level of the centre of the pictorial field of action, he is soon fatigued, and brow-ache and discomfort ensue, for observation requires him to *extend* his head slightly from the " primary position," to raise his eyelids and rotate his eyes upwards.

If now he reseats himself at a higher level (" dress circle " angle), these factors disappear, for now his head is in the " primary position," or slightly *flexed*, a position assumed by gravitation and requiring very little muscular effort for its maintenance.

It has been suggested that the lower seats in a bioscope theatre should be tilted backwards with head rests, so that the necessary

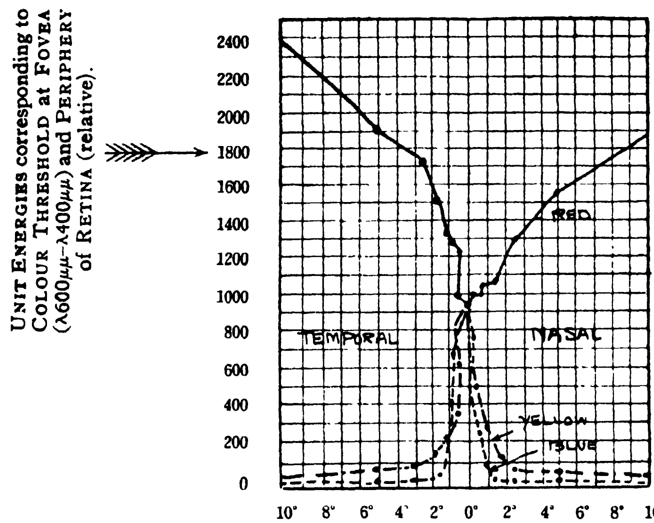

FIG. 1.

Diagram to indicate that the periphery of the retina is relatively less irritable to impact of radiant energy causing sensation of RED light, compared with the FOVEA (direct vision), observing that *the Adaptation phase (Dark or Light adapted) of the Retina does not affect the Red threshold.* The orange-yellow and blue (λ600-400) require the same number of energy units at their threshold of Perception, and are affected by the phase of adaptation of the Retina.

slightly extended position of the head may be attained without muscular effort and so avoid mal-orientation of the head and eyes. However, the promiscuous use of a head-rest in a place of public resort is not a feasible or pleasant proposition.

Fatigue factors, in connection with the observer's posture in using the *microscope*, are also present, and for him no facility is provided for resting his head and neck muscles, and insufficient attention is paid to the angle formed between the ocular and the vertical plane of the observer's head.

In order to avoid mal-orientation and resulting fatigue, it is necessary to provide the observer with a working bench of adequate height, correlated *height* and *position* of chair, suited to the physique of each observer.

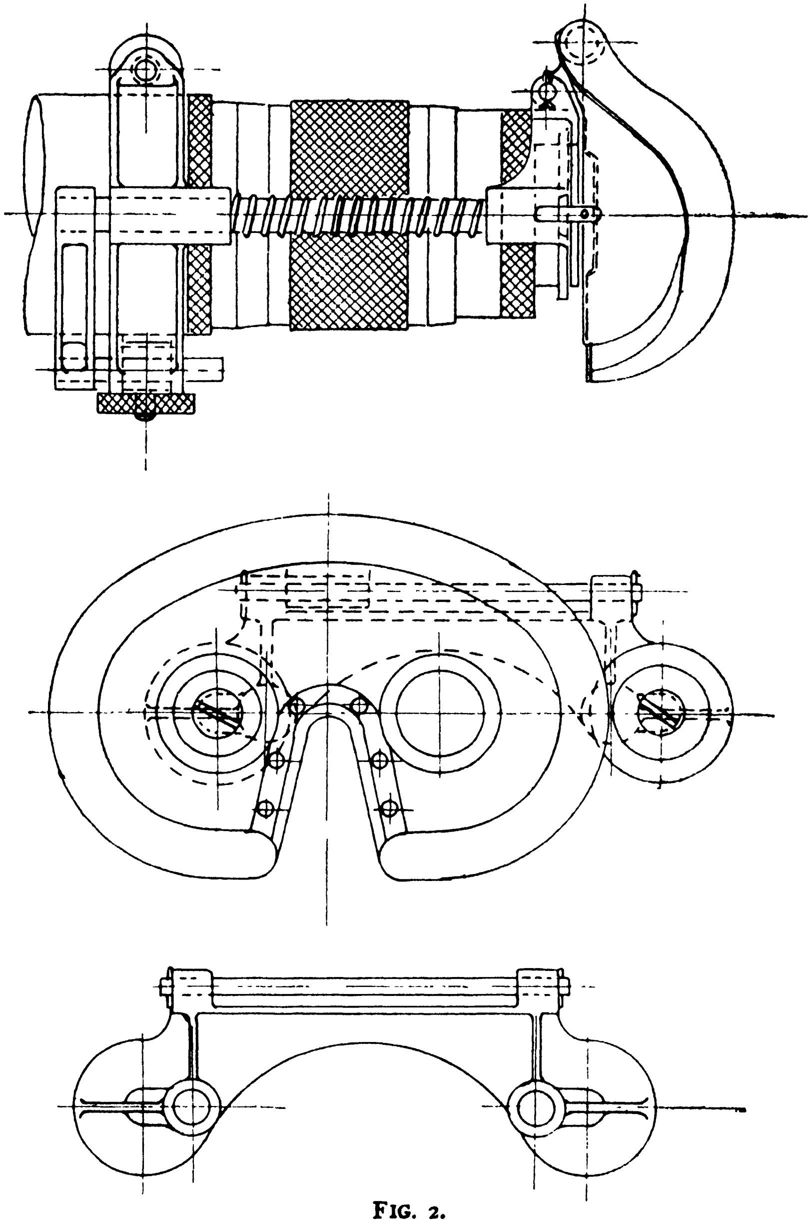

FIG. 2.

DYOPTIKON (PIVOTAL) HEAD-REST
(Universal Letters Patent).
Scale —One-Half.

I have put in as an exhibit a working model of a headpiece attachable to any standard tube microscope without necessitating any structural alteration in existing patterns, although it is intended to arrange a bracket with attachment at or below the trunnion, in any new pattern microscope available. Diagram and models illustrating application of this dyoptikon head-rest (eye-piece) to telescopes, etc., are also shown. (Fig. 2.)

I am also showing, by permission of Professor A. D. Waller, F.R.S., his early and original negatives showing the electrical response of retina to impacts of radiant energy of short duration; also solution of so-called "Visual purple" which exists in colloidal solution bathing the receptor organ (retinal cones and rods), a photochemical substance which under the above circumstances of external stimuli presents a balanced reversible reaction, and has been shown to flow into the central fovea where no rods exist. Its "sensitivity" is in accordance with Planck's minimum quantum of energy, and has been shown by Victor Henri to be several thousand times more sensitive to light than the most sensitive photographic plate, on rapid exposure. Spectroscopically, "Visual purple" shows *no absorption bands.*

A group of papers by **Dr. M. W. Travers, F.R.S., Dr. W. E. S. Turner, Mr. Robert Mond,** and **Mr. F. Twyman,** dealt with Optical Glass.

GLASS FOR OPTICAL PURPOSES.

By Morris W. Travers, D.Sc., F.R.S.

I have been associated with the glass industry since the outbreak of war, but the manufacture of optical glass in this country has been a matter of secrecy, and only officials have been admitted to the works, so that persons like myself can know only of what has been done indirectly and by rumour. British scientific literature contains one or two papers, indirectly connected with the subject, and the public and semi-scientific press contains only references to claims to discoveries of "German secrets" by British scientists—and denials that there were any secrets to discover. I hope that the claims are of a more substantial character than those put forward in connection with scientific glassware.

During the past autumn I made a tour of America, where I visited several of the new optical glass plants, to which I was freely admitted, and met many of the men who had been engaged in the development of the industry. During the early years of the war the manufacture of optical glass had been carried on in a rather desultory fashion, but in April, 1917, American industry was suddenly called upon to meet an enormous demand for optical glass. It might have been thought that America would have made use of the information gathered in this country, but an American scientist who took a leading part in developing the industry told me that this was not the case, for "we understood that your Government had a lot of information on the subject of optical glass, but we could get nothing out of them at all."

America was, however, in a very advantageous position from which to attack the problem. In the first place there were ample funds for research, administered by a thoroughly scientific body, the National Research Council, and not by a Government Department, scientific only in name. In the second place there already existed the organisation of the Geophysical Laboratory of the Carnegie Institution. Of the work of this institution the Report of the Director for the year 1918 speaks as follows:—"Suffice it to say that with a group of 20 scientifically trained men, all trained in handling silicate solutions at temperatures required for the making of glass, and familiar with the control of most of the important factors in the problem, it proved practicable to make rapid progress, and in June following, after two months of concentrated effort, the gross production of glass by a leading manufacturing firm had increased from 15,000 to 28,000 pounds per month, and in quality had improved to such an extent that rejections by Government inspectors became comparatively rare." The results are really expressed in the last sixteen words of the quotation.

The rapid progress made in America was largely due to the fact that the scientists of the Geophysical Laboratory, and of the Bureau of Standards, were not content to sit on High Olympus in the suburbs of Washington, but did their work in the manufacturing plants, from which the results of their researches are issued. Thus science and industry co-operated in the closest possible manner, with results which speak for themselves; for not only were the practical results aimed at actually achieved, but a very large volume of scientific research was carried out, much of which has already been published in American scientific literature, while much more awaits publication.

We have certainly done good practical work in a limited field in this country, and nothing pleased me more than to hear the quality of some of our British scientific glass praised in America. The greater credit to those to whom the results are due, who have worked, as Englishmen often work best, in face of difficulties. Given the opportunity, the British scientist is equal to any in knowledge, and superior to most in grit; but the policy adopted by our Government Departments of attempting to monopolise science, and draw a dividing line between science in the university laboratory and science in the works, is fatal both to scientific and industrial progress.

GLASS FOR OPTICAL PURPOSES.

By W. E. S. Turner, D.Sc., M.Sc.,

Of the Department of Glass Technology, Sheffield University.

It is with great reluctance that I find I must forgo the pleasure of being present at the Symposium on Wednesday next.

I am glad to know that some members of the Society of Glass Technology will be present and take part in the proceedings. The fine array of papers is a tribute to the great efforts Sir Robert Hadfield has made to direct the attention of scientific men to the importance of encouraging the production of all-British optical instruments.

Amongst the large number of papers, however, I do not find a single one dealing with the manufacture of optical glass. It is, in my opinion, unfortunate that there should not be as free and ready a discussion of this subject as had taken place in America in these past three years.

I should like to make some remarks of a very general character to indicate to makers and users of instruments the position in which optical glass makers frequently find themselves. There is, in my mind, not the slightest doubt that we can produce in this country all the types of glass requisite for microscopes and other optical instruments. The long experience of Messrs. Chance Bros., and the splendid achievements of the new Derby Crown Glass Co. undoubtedly demonstate this.

The amount of optical glass in any one instrument is, as a rule, quite small, whilst for the instruments of high precision, even the total amount of glass called for by manufacturers is very small. The glass maker, however, knows that in order to ensure homogeneity, freedom from striae, etc., from the glass, he must make a melt on a considerable scale. Further, some designers of optical instruments will call for a new glass of special properties, may be, for example, one which is successful in eliminating light rays between certain wavelengths. The production of such a glass calls for considerable research on the part of the glass manufacturer, and he usually cannot expect to sell but a very small quantity when produced, whilst the instrument maker is not prepared to cover the cost. Such a demand cannot always be met by the glass manufacturer; it is in no sense a commercial proposition. For some reason, connected probably with the early days of German competition, the manufacture even of the well-known varieties of optical glass has never been remunerative, although with the recent American products the prices, I believe, have had a more reasonable relation to the cost. One American manufacturer stated that he was prepared to continue the manufacture of optical glass if the loss was not greater than 10,000 dollars per annum, although he was hoping, eventually, the factory costs might be balanced by income.

There is an obvious remedy for the unremunerative rates for optical glass, namely, that instrument makers should be prepared to pay prices sufficient to make the industry financially sound. There is also a means by which special glasses, required only in small quantities, may be made without asking glass manufacturers to go to unnecessary trouble and expense. It lies in the use of the joint resources of the laboratories of the British Optical Instrument Manufacturers' Research Association, under Sir Herbert Jackson, and of the Department of Glass Technology in the University of Sheffield.

The last-named Institution has been equipped in such a manner as to be admirably adapted for making special glasses in smaller quantities than the manufacturer can consider worth while, and meltings up to two cwt. in size can be undertaken. Where it is a matter of importance that a special glass shall be worked out, I urge most strongly that the joint resources of the two laboratories be employed.

In regard to crystals of calcium fluoride, I heartily concur with Sir Robert Hadfield's views that it would be strange if the mineral resources of the Empire could not furnish our requirements. Some time ago I received from a merchant, Mr. B. Moss, 21, King Street, Covent Garden, London, W.C., a beautiful specimen of crystalline calcium fluoride from a mine in the neighbourhood of Johannesburg. I am forwarding specimens of this to you. When I say that the specimen was sent with the object of obtaining a market amongst manufacturers of common glass articles only, it will be agreed that the source may be worth further exploitation for optical specimens.

The manufacture of optical glass in America, taken up only during the war, is still a long way behind ours in output and variety. Recently I was able to visit practically all of the war plants. The number of types of glass made so far is limited, and in the last few months all the plants except that of the Spencer Lens Co., at Hamburg, New York, and the new experimental plant at the Bureau of Standards, Washington, have closed down. For a long time, therefore, there should be in America an important market for optical glass made in this country.

NOTE ON FLUORITE.

BY ROBERT L. MOND.

Our Chairman, Sir Robert Hadfield, has asked me to ascertain whether crystals of fluorite suitable for optical purposes, of which there is a great shortage, are obtainable in the Dominion of Canada.

I at once got into communication with my friend, Mr. C. V. Corless, the General Manager of our nickel mines in Canada, who succeeded in ascertaining for me the following facts.

Crystallised fluorite is exceedingly scarce in Canadian deposits, and there only appears to be one property of any promise in Canada. Mr. Gavin M. Wallbridge, owner of the Wallbridge Mine, Madoc, Ontario, has sent me one crystal, which I herewith submit. In this mine there are two veins, which contain some beautiful, pure white crystals; he has supplied some of these crystals to Messrs. Bausch and Lomb, of New York. The crystal he has sent me he states to be from the second vein. This property is flooded at the present moment, and he cannot work it until next Spring. If material slightly off colour would be suitable, he would be in a position to supply straight away, but the clear white he could not supply before next Spring.

The vein is a closely packed one, tight from wall to wall, and in using dynamite to loosen the ore, all the crystals within a few feet of the shot hole are shattered. He is sometimes able, however, to locate a rough hole after mucking operations, and with great care and a lot of time he is able to save some beautiful specimens. He continues to state that the price which he obtained last year was so much less than the value stated by the Bulletin issued in Washington that he became disgusted, and did not bother to make any attempt to save the crystals.

He further states that he has not an expert there to place a value on the crystals, and, in consequence, must trust to the business honesty of the consignee. He has no doubt that a British firm would "play the game." He is much interested in the crystals end of the business, and would be very pleased to hear if the slightly off-coloured crystals would be of any use, and what would be the smallest size worth submitting.

I am also in receipt of a letter from Mr. Thos. Gibson, Deputy Minister of Mines, who has interviewed the brother of Mr. Wallbridge. He informs us that the deposit is very limited, and that the deposit not now being worked was much more promising. Mr. Gibson's impression is that we cannot count upon the Madoc Mine furnishing any commercial supply of the special type of fluorite, unless the demand is extremely small.

The material is undoubtedly fluorite, and I have submitted the sample to Messrs. Swift and Sons, who propose cutting a lens or prism from it to ascertain its optical properties.

Although the actual specimen is a large crystal, there are only relatively small portions of it which appear to me suitable for optical use. As this crystal was sent to me from Canada in a canvas bag, it may have suffered crushing in transit.

I regret I have not been more successful in obtaining information as regards the occurrence of this mineral.

THE ANNEALING OF GLASS.

By F. Twyman.

Although owing to the small sizes of microscope lenses, and the fact that they are usually cut out of comparatively massive pieces of glass, want of annealing is very unlikely to cause the microscope maker any trouble, yet a few remarks relative to the principles underlying the annealing of optical glass may be of interest, if for no other reason than that the same principles underlie the efficient moulding of glass (or indeed of other materials), and there is no reason why an appreciable saving in the cost of manufacture of microscope objectives might not be effected by high quality moulding.

When the Research Laboratory of Adam Hilger, Limited, took up the question of annealing glass in 1915, we were unable to discover that any research work of a fundamental character had been done on the subject. We were unable to find even a clear presentation of the cause of faulty annealing. For various reasons we have not published a full account of the work, but the principles involved and some of the results as applied to glassware will be found sufficiently fully described in a paper read before the Society of Glass Technology in 1917. ("The Annealing of Glass," by F. Twyman. *Trans. Soc. Glass Technology*, 1917. I. 61, *et seq.*)

The phrase "badly annealed" when applied to glassware implies the presence of internal stress.

When glass is in a definitely molten condition there can be, of course, no permanent internal stress. Moreover, it can be shown, by keeping a suitable glass object under observation in a tube furnace, that even when the glass is cool enough to be practically solid under such stresses as are occasioned by its own weight, it may yet be mobile enough for severe internal stresses to disappear in a few minutes. On the other hand, at ordinary air temperatures glass is almost (though not quite) perfectly elastic.

But between this high temperature, where the glass is so mobile that internal stresses are evanescent in, at most, a few seconds, and the low temperatures, where the glass behaves as an elastic solid, is a region where internal stresses take, say, a minute, or an hour, or a few hours, to die out. It is this range of temperature which is important in annealing, and an accurate knowledge of the mechanical properties of the glass throughout this region is necessary if we are to attain any specified perfection of annealing in a minimum time, and without distortion of the articles. This region I call the annealing range.

If it were possible to cool any glass object from the high temperature down to ordinary air temperature in such a way that the temperature remained uniform throughout the mass, then no matter how fast the cooling the glass would be well annealed.

What actually happens is that differences of temperature exist while the glass is cooling. The stresses so caused are transient, so long as the glass is within the annealing range; but when eventually it becomes cold and the temperature uniform, there are present permanent stresses depending on the variations of temperature throughout the mass which existed while the glass was cooling.

To anneal glass, then, it is necessary to keep it within the annealing range till the stresses have died out, and then to cool it with sufficient slowness. No kind of heat treatment which does not raise a badly annealed sample of glass to within this range will greatly affect its condition of internal stress, whether for good or ill, in any reasonable time.

The method developed in our laboratory for determining the annealing temperature will be found in the paper cited above. The steps in the argument may be briefly summarised.

The degree of annealing to be attained, and the time in which it is to be accomplished must be defined. For glassware we have laid down the condition that at the annealing temperature 95 per cent. of the original stress must disappear in three minutes. For optical glass appropriately modified stipulations are adopted.

The case of the disappearance of stress in a viscous body was considered by Maxwell,* who gave an exponential expression applicable to such cases connecting stress with time, thus

$$F = ESe^{-\frac{t}{T}}$$

where S is a distortion or strain of some kind produced in the body by displacement, F is the stress thus excited, E is the co-efficient of elasticity for that particular kind of strain, t the time, and T a time named by Maxwell the time of relaxation, which depends on the nature of the body.

The product ET he calls the co-efficient of viscosity, since in the case of steady progressive strain or distortion produced by constant stress the rate of strain multiplied by this product gives the stress.

It is obvious, then, that by defining the annealing temperature in the way we do, we have at the same time defined a viscosity. All we have to do, then, is to find the temperature at which the glass has the viscosity so defined, and we have the annealing temperature.

For details of apparatus and method the paper mentioned above must be referred to; but one point may be of interest.

It was found by us that in the neighbourhood of the annealing range most glasses examined double in mobility for every 8° C. rise of temperature, approximately. If then an attempt were made to anneal at 500° C. a glass whose annealing temperature (as defined above) is 580° C., the glass would require to be left one thousand times as long in the former case as in the latter.

The Research Laboratory,
Adam Hilger, Ltd.

* Phil. Mag. S 4. Vol. 35. Feb., 1868. p. 129.

APPLICATIONS OF THE MICROSCOPE.

The following papers and communications dealt with recent developments in the applications of the microscope, particularly in industry.

This portion of the Symposium was introduced by the presentation of a paper on "The Great Work of Sorby," by **Sir Robert Hadfield, Bart., F.R.S.**

THE GREAT WORK OF SORBY.

By the President of the Faraday Society

(SIR ROBERT HADFIELD, BART., D.SC., D.MET., F.R.S.).

Early Work; Researches on Metals; Researches on Rock Sections; Work on Meteorites; Application of Sorby's Work to Metallurgy.

IN the First Sorby Lecture "On Some Structural Analogies between Igneous Rocks and Metals," read before the Sheffield Society of Engineers and Metallurgists in February, 1914, Professor W. G. Fearnsides, M.A., F.G.S., rightly said that the audience had met together to honour the father of Modern Petrography, that citizen of Sheffield, Henry Clifton Sorby. Professor Fearnsides has dealt with the subject in such an excellent manner and given so much valuable information in his lecture that I quote him very fully.

Early Work.—Sorby's earliest Research Work was in 1849 when he prepared the first rock slice ever made, and his first microscopical study of igneous rocks was presented in his historic Paper read before the Geological Society of London on December 2nd, 1857. His attempts were received almost with derision, some of the Members present saying that he was drawing largely on their credulity. Later he was thoroughly avenged by the Geologists of all Nations who assembled to celebrate the Centenary of the Geological Society of London when Sorby on the results which were formerly derided was acknowledged and acclaimed by them to be the founder of modern Petrography.

Researches on Metals.—Sorby began his work on Metals in 1863 and lectured about it in Sheffield before the Literary and Philosophical Society in February, 1864 ("On a New Method of Illustrating the Structure of Various Kinds of 'Blister Steel' by Nature Printing," Sheffield Lit. & Phil. Soc., 1864). Unfortunately there is no trace of this in the Proceedings. My own impression is that this Paper was

one which was read before the National Science Section of that Society, but no copy was kept of it. When residing chiefly in Sheffield I was a Member of this Section, often meeting Dr. Sorby there. It is now no longer in existence.

Later on Sorby communicated his results at the Bath Meeting of the British Association ("On Microscopical Photographs of Various kinds of Iron and Steel," B.A. Report, 1864, Pt. II, page 189). In this Paper the Author briefly explained how sections of Iron and Steel might be prepared for the Microscope so as to exhibit their structure to a perfection that left little to be desired. He also exhibited a series of photographs taken by Mr. Charles Hoole illustrating the various stages in the manufacture of Iron and Steel and describing the structures which they presented. They showed various mixtures of Iron, of two or three well-defined compounds of Iron and Carbon, of Graphite, and of Slag; and these, being present in different proportions and arranged in various manners, gave rise to a large number of varieties of Iron and Steel differing by well-marked and very striking peculiarities of structure.

For 22 years the observations attracted little or no attention and when in 1877 Professor Martens, Berlin, and later M. Osmond and M. Le Chatelier, Paris, began to study metals with the Microscope they had to develop independently and anew the craft which Sorby had invented many years before. Sorby lectured on "The Microscopical Structure of Iron and Steel" at Firth College, Sheffield, in October, 1882, and stated that in view of the knowledge of fresh facts he had re-examined the whole of his specimens with improved Apparatus. In 1885 by the use of Lenses of high resolving power and large magnification he first discovered the true composite nature of the "Pearly Constituent" of steel as an aggregate of parallel plates, which discovery may be reckoned the crowning achievement of his microscopical research. Sorby announced this discovery to the Iron and Steel Institute in 1886, "On the Application of Very High Powers to the Study of Microscopical Structure of Steel," Journal of the Iron and Steel Institute, Vol. I, 1886, pages 140 to 144. Subsequently he presented to the same Institution his great Paper "The Microscopical Structure of Iron and Steel," giving a full account of his methods and the results he had obtained. (Journal I.S.I., Vol. I, 1887, pages 255 to 288). These Papers proved to be the signal for great activity in the field which he had so brilliantly started to explore, but it was really far back in the 'sixties that Sorby originated the Science of Metallography. His work at this period gave cause for an American writer in 1900 to say of him (in the "Metallographist" of April, 1900, Boston, U.S.A.): "Whatever has been accomplished since in microscopic metallography has been done by following in his footsteps. To Dr. Sorby and to him alone is due the pioneer's honour."

Researches on Rock Sections.—At the period (1849) when Sorby began his researches on rocks, the only available knowledge of the constitution of igneous rocks was that gained either by the field-worker with his hammer or by the indoor Geologist by the tedious processes of chemical analysis. Slices of rock

ground to a thinness of about one-thousandth of an inch allowed light to pass, and with the Microscope it became possible to see their structure more clearly than the texture of the coarsest granite had hitherto appeared. Rock-slices, having been ground down flat, were admirably adapted to the application of polarized light, and to one who had already a working knowledge of optics, the vagaries of the vector variations of the optical properties of minerals proved to be no deterrent. Finding no treatise on this subject ready-made, Sorby designed, and, with his own hands constructed, a polariscope to work either with parallel or with convergent light, and the very instrument which he then made is still in use in the Sheffield University Physical Laboratory.

Researches on Meteorites.—Subsequent to his early Petrological Researches, Sorby turned his attention to the Microscopical Study of Meteorites.

In his Paper "On the Microscopical Structure of Meteorites" (Royal Society Proceedings, 1864, p. 333) he pointed out that he had applied to the Study of Meteorites the principles he had made use of in the investigation of terrestrial rocks described in his various Papers and specially in that on the Microscopical Structure of Crystals (Quarterly Jnl. Geol. Soc. 1858, Vol. XIV, p. 453). He there showed that the presence in Crystals of "fluid, glass, stone, or gas cavities" enabled the conditions under which the crystals were formed to be satisfactorily determined. There were also other methods of enquiry still requiring much investigation and a number of experiments to be made, but not wishing to postpone the publication of certain facts he gave a short account of them in this Paper.

This Paper was followed by another "On the conclusion to be drawn from the Physical Structure of some Meteorites" (B.A. Report, 1864, p. 70), in which Sorby pointed out that he had previously shown that the earliest condition of meteorites of which their microscopical structure furnishes evidence was that of igneous fusion. There were, however, some, like the Pallas Iron, consisting of a mixture of Iron and Olivine which apparently strongly opposed this view if judged from what occurred when melted artificially; for then the Iron being so much more dense would sink to the bottom and the Olivine rise to the top like slag in a furnace. The object of this Paper was however to show that this difference in density depended on the force of gravitation and that, on the surface of a small planetary body, or towards the interior of a larger planetary body, Iron and Olivine might remain mixed in a state of fusion long enough to allow of gradual crystallisation. Such meteorites should therefore be considered evidence of fusion where the force of gravitation was very small; and this conclusion might be valuable in deciding between rival theories of their origin.

Application of Sorby's Work to Metallurgy.—At the time these researches were carried out, although the Science of Metallurgy had advanced at a great rate, Chemical analysis remained the ultimate arbiter of the quality of any metal. The work, however, of Gore,

Barrett and Tchernoff on the intimate relationship existing between recalescence and the hardening of steel, and also the work of Guthrie on eutectics led to the idea that both igneous rocks and alloyed metal are the products of the crystallisation of mixed solutions. Bunsen, and subsequently Vogt of Christiania, called attention to the laws which control the crystallisation of minerals in slag, and when Teall in 1888 pointed out the similarities of structure between graphic intergrowths and Guthrie's eutexia of Metals, the application of the solution hypothesis to rocks became apparent. In the domain of Metallurgy, the introduction of the Thermocouple by Professor le Chatelier led to the study of the Thermal Changes which accompany physical or chemical variations of constitution within the metal.

Sorby, in his Paper contributed to the Iron and Steel Institute in 1887 and published in Vol. I of the Journal for that year, stated :

"It is now twenty years since I commenced to carefully study the microscopic structure of Iron and Steel. The first object was the study of meteoric iron, but I soon found that the results were of even more value in connection with practical metallurgy."

Again, on page 276 of the same volume, he says :

"I regard that even a power of 400 linear fails to show whether the pearly constituent remains unaltered or broke up into very fine laminæ when very suddenly cooled. It either does not or the laminæ are too thin to be recognised. The changes in structure produced by hardening deserve far more study, but will I fear tax to the utmost the capabilities of the Microscope since the constituent grains of hardened steel are so extremely minute."

At this stage Sorby's work on Metals received recognition and exerted a powerful influence. It became evident that the mechanical properties of Iron and Steel depend upon the properties of their crystalline constituents, and at this period the nomenclature of metallography was developed. The subsequent work of Raoult, Van't Hoff, Gibbs, etc., led to a tendency to decry the nomenclature as unscientific. Nevertheless, it is still used and serves well for the ready specification of different qualities of steel.

Professor Judd, who was a friend of Sorby, has given some interesting reminiscences of the conditions under which Sorby worked. Apropos of Sorby's Laboratory, he remarked: "You speak of Sorby's laboratory. All his work, when I knew him, was done in a private room in his house; there everything was as simple as Wollaston's —a table with his Microscope, and a few bits of apparatus lying about."

In the same connection, Judd also remarked : "I went to Sheffield, as a Chemist to the Cyclops Works, straight from the Jermyn Street School of Mines in the Summer of 1864, and at once met Sorby. He not only taught me to make rock-sections, but showed me what he was doing with artificial irons—led to it by his studies of iron-meteorites. Mr. George Wilson, then manager of Cammells, a very enlightened man, gave me permission to supply Sorby with any irons that I analysed, for his work, so that I saw the beginning of his Metallurgical work—a very pleasant reminiscence. Down to the time that Ward

and I left the Geological Survey, in 1871, Microscopic Petrography was always ridiculed by 'the powers that were.' They always said, 'You can't study mountains through Microscopes.'"

The following appreciation of Sorby's work is made by M. Ch. Frémont, the well-known French Engineer and Metallurgist:—

"It was Sorby's discovery of the method whereby the structure of a metal was laid bare to microscopic examination that gave him the right to the title. The method he used to prepare his rock sections failed him with metals, because the latter, even in very thin sections, are not transparent. Sorby, however, discovered that by suitably etching a perfectly polished surface of metal the structure was revealed to microscopic examination." The great merit of Sorby consisted in having applied to Metallurgy the Micrographic method he had discovered and introduced in the study of Mineralogy.

Our Meeting this evening is a living evidence of "Great is the Truth and it will Prevail." From the humblest of beginnings this method of research has grown into a giant. It will still further help to add to the sum total of human knowledge from which all may benefit. All honour to this Great Englishman for the magnificent work he accomplished.

THE REQUIREMENTS OF THE PETROLOGICAL MICROSCOPE.

By Dr. J. W. Evans, F.R.S.

The Petrological microscope is constructed to serve two purposes. It is employed, in the first place, as an ordinary microscope, to observe the form and structure of the smaller features of rocks; and it is also used as an optical instrument for studying the action of minute crystals on light with a view to their identification. The latter function requires special features of greater or less complexity. The exact nature of these arrangements depends, however, to some extent on whether the material is examined in the form of a thin section of a rock, or in minute grains or fragments.

In all petrological microscopes provision is made for the examination of the object between crossed nicols, and for the rotation of these or of the stage or of both alternatively. The advantage of a rotating stage and stationary nicols is so great from the point of view of simplicity of construction, that it is always adopted in the cheaper instruments, and it is quite satisfactory in all cases where the work is confined to thin sections and methods involving certain special accessories or arrangements are not required to be employed.

On the other hand, for the examination of grains mounted in oil or other highly refracting medium, the use of a stationary stage and rotating nicols is practically a necessity, if high powers are to be employed, unless the Nachet device is adopted, by which the objective is attached to the stage and rotates with it. Rotating nicols are also necessary for the more complex optical methods, especially those that require an axis of rotation at right angles to the optical axis of the microscope, as when the optical characters of crystals are studied by means of the theodolite or " universal " stage. It deserves consideration whether, when rotating nicols are employed, a rigid connection between them should not be substituted for the gearing employed by Dick, even although the former is open to the objection that a rotation through a complete circle is not possible. This course has been occasionally followed.

Where crushed material or small grains are examined in oil or micro-chemical tests are applied, the microscope should be protected by a shallow glass bath with a plane floor, large enough to hold the glass slip.

There should be a " mechanical stage " providing for the move ment of the object in two directions at right angles to each other and to the optic axis of the microscope, so that the position of the object may be varied while its orientation remains unaltered. These movements and the fine adjustment should be accurately graduated.

Arrangements should also be made by which a nicol may be placed in a position above the eye-piece. At the same time a slot should be provided at the focus of the eye-piece, so that accessories, such as quartz wedges, may be inserted in focus. The upper nicol or analyser, wherever placed, should be capable of rotation, either simul-

taneously with the lower nicol or polariser or independently of it, and there should be special facilities for adjusting it at small angles of divergence from 3 to 6 degrees from the position of crossed nicols.* This is useful in determining the exact position of extinction.

Greater facilities should be given for the study of the interference figures in the "directions image" in polarised light. It is difficult to exaggerate the value of the purely qualitative results described by Beck, as well as the quantitative methods which involve careful measurements of the "isogyres" or dark bars.† For these purposes immersion objectives with an especially wide angle should be used with highly refracting liquids, and a corresponding wide-angled illumination should be provided. It is absolutely necessary that the student should be in a position to isolate the light from minute crystals surrounded by others of different composition or with different orientation. Among othr examples may be mentioned the zones and twin lamellae of plagioclase. By far the best means of effecting this is by inserting a diaphragm in the focus of the eye-piece and a Becke lens placed above it.‡ This should be a recognised accessory with all except the most elementary petrological microscopes. Provision should be made to enable the exact course of the isogyres to be measured. There is no space here to discuss the merits of the different devices which have been suggested, including one for which I am responsible.§

Some arrangements should also be available for the study of the object in linear convergent light, which is advantageous for various purposes. It can be obtained by employing an ordinary convergent system and inserting a narrow slit in a focus conjugate to infinity, with such orientation relatively to the object as may be required.||

Provision should also be made for the use of monochromatic light when desired. The slit already referred to may be employed for the purpose in conjunction with a prism; or some form of monochromator, or a colour screen may be substituted, unless coloured flames be preferred.

I have not attempted to deal with all the numerous accessories which have been employed or suggested in petrological work, but have confined myself mainly to variations of construction necessitated by special methods.

Reference may be made to the report of the Microscope Committee of the British Science Guild giving a specification of a student's petrological microscope.¶

A serious difficulty is presented by the high cost of petrological microscopes constructed so as to allow of the application of advanced methods of research. This is inevitable so long as the number of instruments manufactured is too small to justify the employment of systematic standardisation with interchangeable parts.

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* F. E. Wright, Am. Journ. Sci., Vol. 26., pp. 349-368, 380-386 (1908).

† Min. Mag., Vol. XIV, pp. 230-234, 276-281 (1907); Min. Patr. Mitt., Vol. XXIV, pp. 1-34 (1905).

‡ Min. Mag. Vol. XVIII, pp. 45-51 (1916).

§ Mineralogical Magazine, Vol. XVIII, pp. 52-57 (1916).

|| Min. Mag., Vol. XVIII, pp. 130-132 (1917).

¶ Journ. Brit. Sci. Guild; November, 1916, pp. 28-31.

There are two directions in which we may look for an increase in the demand for instruments of this type. The first is the general adoption by chemists of optical methods of studying crystalline chemical products, and the second, the stimulation of the demand for British instruments in other countries. Every encouragement should be given to those engaged in original scientific work to design new or improved types of microscopes or accessories, and each new type should be fully described in the scientific and technical journals by the inventor, whether he is a member of the staff of a University or of that of an optical factory. If this policy is effectively pursued, other countries will turn to British makers for the supply of instruments of the latest and most novel patterns.

It was by such methods that the well-known German makers obtained the commanding position they held before the war, and it is only on these lines that our country can hope to take the place that it ought to have in the manufacture of specialised types of microscopes.

The working out of new ideas involves, however, considerable expense, far greater than is afterwards required to construct similar instruments when standardised and produced on a large scale, and it is absolutely necessary that pecuniary assistance should be, in the first place, forthcoming, if success is to be ultimately achieved.

APPLICATION OF THE MICROSCOPE TO THE SELECTION AND CONTROL OF YEAST EMPLOYED FOR BREWING PURPOSES.

By A. CHASTON CHAPMAN.

The application of the microscope to the selection and control of yeast in the brewery may be said to date from the publication in 1876 of Pasteur's " Etudes sur la Biere." In this he made his famous pronouncements " That every unhealthy change in the quality of beers coincides with the development of micro-organisms foreign to brewer's yeast properly so-called," and that " the absence of change in wort and beer coincides with the absence of foreign micro-organisms."

By " foreign micro-organisms " in the above statements Pasteur referred solely to bacteria, and it was some years later (1879) that Hansen outlined his method of making pure cultures of yeast starting from a single cell. As a result of the application of this method, he showed that some of the yeast species which were frequently present, both in the pitching yeast of the brewery and in the air, were capable of producing " diseases " in beer quite as serious as those produced by bacteria. By a study of ascospore formation and other biological characters of the various species, it was found possible to make a distinction between the culture yeasts and the so-called " wild " yeasts sufficiently definite to enable one cell of the latter to be detected in the presence of at least 100 cells of culture yeast. By means of the microscope, therefore, it is possible to detect the contamination of the pitching yeast, not only with bacteria, but also with other undesirable yeast species, and to take the necessary steps to purify it.

Lantern slides representing culture yeasts and a number of the " wild " yeasts in illustration of the above statements were shown.

THE MICROSCOPIC OUTFIT OF A TEXTILE RESEARCH LABORATORY.

By R. S. Willows, M.A., D.Sc.

In the interests of brevity I will confine my remarks closely to the requirements of a research worker in the textile industry. The materials to be examined are fabrics, yarns, fibres, starches, and

Objectives.

The objectives used will be from 2 in. down to an oil immersion, and for certain purposes an ultra-microscope of the cardioid or similar type, while for special work an immersion ultra-microscope may be a great advantage. The most useful lenses are the 16 mm., the 6 mm., and in a less degree the 4 mm. and an oil immersion. The first is most useful for examining single fibres, while the second will do most of the routine work on sections, especially if it will stand a high power eye-piece. Strange to say, at least one English maker of high-class lenses does not produce a 6 mm. lens. I have found certain English apochromats excellent in flatness of field and definition, but they have the disadvantage of a short working distance; it is fair to add that in the last respect they are no worse than Continental types. For most purposes I find some semi-apochromats in my possession are all that is required; the field is not very flat, but the definition in the centre is excellent, their working distance is large, they will stand an $\times 18$ eye-piece, and they are comparatively inexpensive.

Stands.

I prefer the English type of stand to the Continental model, on account of the better distribution of weight and consequent greater stability, and also for the greater space for the substage. The tube must rack out to take a 2 in. objective, and in this connection it is a great advantage if the stage can also be racked. The latter movement is also very useful when it is required to use vertical illumination. A mechanical stage, centering substage, and high-class condenser are taken for granted, even on the simplest types of stand. Very frequently a considerable portion of the slide has to be examined; this should be possible without fouling the condenser.

As the material to be examined has frequently to be submitted to the action of acids and alkalis while it is on the stage, the latter should be made of a suitable material, and should be designed so as to eliminate as far as possible the chance of injury to the instrument. Apart from material used, the design of such a stage appears to have received little attention. It is in such examinations that a large working distance for the objective is so markedly advantageous.

Polarisation Apparatus.

This is often extremely crude. Types which require the analyser to be screwed on behind the objective, or in which the polariser replaces the condenser, not only waste much time in making the necessary changes, but the illumination is cut down badly. The analyser should be built in the body tube, should be capable of being swung or slid out when not required, and the analyser should come below the condenser and should have the swing-out motion.

Ultra-microscope.

An efficient and easily handled form of ultra-microscope is urgently required, not only for general scientific research, but also in several branches of textile work, especially on the sizes and dyes.

Photomicrographic Apparatus.

It is on this side that English apparatus is most defective. Where it is not a frank imitation of foreign types, it shows no evidence of design as a whole, and in a number of small details is so defective that I sometimes doubt if its makers have ever used it to take photographs under the varied conditions that exist in a works research laboratory. For my own purposes I desire an equipment fulfilling the following conditions:—

(1) As it will be used where there is considerable vibration, the mechanical design should be such as to reduce the effects of this vibration to a minimum. That eliminates the type where camera and microscope are on separate stands.

(2) It should be easy to make a visual examination before the photograph is taken. This is most readily done by swinging the optical system and microscope out of line with the camera. It may be difficult when the light source is a large arc surrounded by a lantern, but is comparatively easy if a "Pointolite" set is used. I have found this source most efficient and handy. It consists, as is well known, of a tungsten arc in nitrogen; it burns for hours without the slightest attention, and as the spectrum of tungsten is exceptionally rich in the photographically active rays, it is more powerful than a simple candle-power measurement indicates. May I suggest to manufacturers that before it is fixed on the optical train they should discover in what direction it emits most light, and fix it accordingly? At present the direction used appears to depend on other considerations altogether.

(3) It should be possible to pass from transmitted to vertical illumination quickly and without having to make a number of delicate adjustments. Among the unsatisfactory methods at present put on the market I have come across the following:—(a) Change the microscope to a vertical position and use a vertical camera; (b) swing the optical train through a right angle round a vertical axis; (c) move the optical bench parallel to itself and insert a mirror inclined to the beam at 45°. The last is undoubtedly the method requiring the least complication of apparatus if properly designed;

but some of the applications of it are very crude. A fourth method appears to be possible, *viz.*, to keep the optical train fixed, but to deflect the light three times at right angles by total reflexion prisms, and so throw it into the vertical illuminator. As the last prism would be a small one, it could well be carried by the moving part of the microscope; it would not then require adjustment as the microscope is focussed.

(4) It would be a great advantage where the action of solutions is to be followed and recorded, if a horizontal camera could be used when the slide carrying the object is horizontal; this would combine the advantages of a horizontal camera and a vertical position for the microscope tube. I have not seen any attempt at this in an English apparatus.

In conclusion, may I say that the textile industries in the past have been among the least scientific of the large trades, but the need for research is now fully recognised. In such research the microscope and physical apparatus generally must play an important part. As one who is keenly interested in the technical applications of science, I hope instrument makers will make themselves acquainted with the requirements of the industry and will endeavour not only to meet them, but, if possible, to anticipate them. As a small step in this direction I suggest that *The Journal of the Textile Institute* should find a place on the shelves of their works library.

A series of papers dealt with the use of the microscope in metallurgy. The subject was introduced by **Dr. W. Rosenhain, F.R.S.**

In view of the lateness of the hour, there will not be time for me to read the paper which I have prepared; therefore I will only deal with one or two points which I think are more relevant to the aspects of the whole question which have already been discussed. I should like to say one or two words with regard to the question of increased magnification and increased resolving power for metallurgical work. There can be no question that we are dependent to a large extent for further progress in certain directions in metallography on obtaining higher resolution and higher magnification, but it has been clear to many of us for a long time, and to those to whom it has not been clear it will be so after having listened to these discussions, that magnification alone is quite useless, and that what we must look for is higher resolving power. Mr. Barnard has emphasised the theoretical possibilities of using a much shorter wave-length. No doubt in the future it may be possible to do that, and Mr. Barnard himself has been singularly successful in utilising the short wave-length of invisible light for photomicrographic work on transparent sections. About seven or eight years ago I was able to obtain at the National Physical Laboratory a complete outfit of Zeiss apparatus for this purpose, and I spent a large amount of time—over a year—in endeavouring to use it for metallographic purposes, but the result on the whole was extremely disappointing. I succeeded in getting a few photographs, but the time occupied and the labour involved were enormous, and when I did succeed it was only with moderate magnifications. The attempt to use high power monochromatic immersion lenses failed entirely, owing to the fact that I always got milky images. Fluorescence occurred whenever the ultra-violet light struck any object within the tube. When the beam of ultra-violet light has to be sent through a reflector and through the objective, fluorescence occurs on the objective itself, and as a result the light reflected from the back of the objective all over the tube—the actual visible light due to that fluorescence—became very serious in its actinic effect on the photographic plate, and I felt the only possibility of proceeding at all would be if a filter could be obtained which would exclude visible light and transmit the ultra-violet light almost undiminished. Prof. R. W. Wood, of Baltimore, suggested the silvering of one of the lenses, but that increased the exposure so enormously that it was hopeless. Other circumstances arose, and the matter had to be left aside. I hope someone may succeed in overcoming these difficulties, but I am not sanguine of the results which can be obtained with any kind of invisible radiation, and my reason is that such methods will only yield photographs. Photographs are extremely useful as a record of what you have seen, but as a means of actual microscopic examination they are not satisfactory. I always think it is necessary to examine successively large areas, and that you cannot, by using a few photographs of small areas, form a really good opinion.

There is one other direction in which I think that higher resolving power is at any rate conceivable. Resolving power is a function of the numerical aperture expressed in terms of u sin α. Sin α cannot be increased very much, but what about u? The immersion liquid is a difficulty, but I think that a higher refractive index for the front glass is at any rate a thing where there is hope of success as the result of research. I agree with Sir Herbert Jackson that research will make it possible to make glasses of almost any desired kind; there is, however, a good deal of emphasis to be placed on the "almost," because the range of possible glasses is strictly confined within certain limits of refractive index. I have on a previous occasion given the values of these limits, and the limitation is due apparently to quite definite physical and chemical causes. Glasses having very low refractive indices or high ones, and having abnormal optical properties, are virulent chemical agents in their action on everything they may come in contact with, including air. They are rapidly attacked by moist air, and they crystallise during manufacture. There, I think, lies the solution of the problem. When we look for substances which have high refractive indices, we find them in crystals, and I want to carry that suggestion one step further. I made it many years ago, but with the renewed stimulus to research in this direction, it is worth making it again. The time has surely come when we should meet this question of crystalline substances for optical purposes by attempting to grow crystals artificially. I am quite sure that it can be done, and it ought to be done. I have made a few preliminary experiments of that kind, and have succeeded in producing some small calcium carbonate crystals. They were small, but they were large enough for short-focus lenses, and I think the idea of growing crystals is not altogether out of the range of practical possibilities to-day

THE METALLURGICAL MICROSCOPE.

By Walter Rosenhain, D.Sc., F.R.S.

(The National Physical Laboratory.)

In a paper* presented to the Royal Microscopical Society in 1906, the present author has described a Metallurgical Microscope in the design and construction of which an effort has been made to apply certain principles which he regards as fundamental for the construction of scientific instruments in general and of microscopes in particular. These principles have previously been discussed in a paper† presented to the Optical Convention, 1905. For the purposes of the present discussion, therefore, it will not be necessary to do more than to summarise briefly some of the principal points affecting the metallurgical microscope.

In regard to mechanical design, the primary consideration is that of providing adequate strength and stiffness not only in the base and limb, but also in the working joints, such as that upon which the limb turns. The design of such an instrument should, in fact, in the author's opinion, be based rather upon that of a machine tool than on the unduly delicate, sometimes flimsy, and often unmechanical devices which are to be found in some scientific instruments. One fruitful source of lack of rigidity may be found in the presence of unnecessary movements; for instance, it is now fairly generally accepted as an essential feature of metallurgical microscopes that the focussing movement, at all events so far as the coarse adjustment is concerned, should be applied to the stage. The provision of a coarse focussing movement for the body tube as well, therefore, constitutes an undesirable duplication. If the fine adjustment is also applied to the stage, as has been done in the author's design, then the body tube can be rigidly attached to the limb, with a corresponding gain in rigidity.

Another source of unsteadiness lies in the manner in which the so-called vertical illuminator is frequently attached. Where this fitting is screwed to the nose-end of the body tube and the objective is screwed into the illuminator, a certain amount of play is liable to occur. The author, therefore, very much prefers an arrangement by which the objective is screwed direct to the body tube, and the illuminator is inserted into the body tube, by means of a slide or otherwise, through a lateral aperture.

The application of the fine focussing adjustment to the stage offers a further advantage which is of some importance, as by this arrangement the fine focussing movement can be placed in an axial position. If this is done there is no overhang to magnify the slight play which is unavoidable on all smooth running slides. This

* "On an Improved Form of Metallurgical Microscope," Journal Royal Microscopical Society, 1906.

† "The Mechanical Design of Instruments," Proc. Optical Convention, Vol. 1, 1905.

difficulty might perhaps be overcome in another way by adopting geometrical contacts instead of plain sliding contacts. The advantage of this system has long been recognised in theory, but instrument makers do not appear to have seen their way to its adoption on any large scale.

The illuminator and its adjustments deserve a little further consideration. Both for visual and photographic purposes the author has found it a very great advantage to have an illuminator whose position is capable of a very considerable range of adjustment. Whatever form of reflector be employed, it is always an advantage to be able to adjust its position not merely by rotation but by lateral and longitudinal movement in the tube. This is important, not only for the purpose of securing illumination at the precise incidence best suited for showing any particular feature, but also for the purpose of eliminating that most fruitful source of difficulties—internal reflections from the lenses of the objective.

Two further features of the mechanical design are of some importance. The first of these is the provision for a large working distance between stage and objectives. This is necessary not only to provide for the examination of thick specimens, but also because for many purposes the use of long focus objectives is necessary. This latter aspect of metallurgical work is assuming increasing importance at the present time owing to the fact that the study of macro-structures is now demanding much greater attention. In many cases these macro-structures are large enough to be photographed with an ordinary camera or even to be reproduced by means of direct contact printing. There are, however, many conditions in which the macro-structure is still sufficiently small to require magnifications of from 2 to 10 diameters, and it is very convenient for those who are not in a position to set up a separate apparatus for this purpose if their metallurgical microscope is capable of being used with long focus objectives working either with or without an eye-piece.

Another matter of some convenience in the metallurgical microscope is the provision of a complete rotation of the stage together with a simple centering device attached either to the stage or to the nose-end of the body tube. Rotation of the specimen is important for two reasons:—In the first place under oblique illumination the aspect of an etched surface varies in a most instructive manner with varying incidence of the light, and it is sometimes convenient to apply coloured illumination from two or more directions, and to be able to rotate the specimens under such illumination. In the second place, when a vertical illuminator is used which covers one-half of the aperture of the objectives, the resolving power is much greater in the direction parallel to the edge of the illuminator than in the direction at right angles to it.

Consequently in examining such a structure as finely laminated pearlite, this may appear uniform or " sorbitic " when viewed in the one position, while it becomes clearly resolved into laminae when turned through a right angle. This, of course, applies mainly to work at high magnifications under lenses of large resolving power.

Turning to the optical equipment of the metallurgical microscope, there can be no question that the requirements of metallurgy demand the best and even more than the best that optical achievements can

provide. The requirements themselves are mainly those common to all microscopic work of the most exacting kind. In regard to the provision of the most critical definition, the highest possible resolving power and the largest and flattest field, together with the greatest possible approach to freedom from colour and the elimination of differences of actinic and visual focus, hitherto the best appo-chromatic lenses have provided the nearest approach to a fulfilment of these requirements. Metallurgical progress, however, undoubtedly tends increasingly to the production of materials having an extremely minute micro-structure, and the differentiation of these and the reading of their life history from their structure, makes increasing demands upon the resolving power of our lenses. The provision of a resolving power which should allow the employment of a much higher useful magnification becomes, therefore, of very considerable practical importance. Whether or not such an achievement is within the range of possibility is a matter for the optician rather than the metallurgist. The difficulties of the problem must, however, be very fully recognised; one of the most important, no doubt, resides in the difficulty of finding an immersion liquid, of very much higher refractive index than the cedar-wood oil commonly employed. The use of monobromonaphthalene immersion objectives has been tried, but they do not appear to have achieved any widespread use. An effort has also been made to meet this requirement by the use of light of much shorter wave-length. The author has spent a considerable amount of time in endeavouring to use the Zeiss ultra-violet microscope for metallurgical purposes, and has succeeded in obtaining a few micrographs by this means. He has, however, abandoned his efforts, because the expenditure of time required was much too great, while the results themselves were not particularly satisfactory. One of the main difficulties in his experience arose from the internal scattering of the ultra-violet light and the occurrence of fluorescence within the microscope tube. Even should it be possible to overcome these difficulties, a process which is entirely photographic, and in which the systematic visual examination of relatively large area of specimens is impossible, does not promise a very large range of utility.

Reverting to the requirements for objectives of the ordinary type intended for metallurgical use, there is one point which requires special emphasis and attention. Clear images, whether visual or photographic, can only be obtained if serious reflections of light from the back surface of the objectives can be avoided. As has been indicated above, this is partly a question of careful adjustment of the light and of the illuminator. With the best of facilities in that direction, however, the author's experience has shown very clearly that different lenses of the same focal length differ very widely in respect of this matter of internal reflections. This appears to be a question of the shape of the back lens of the objective, and especially of the outer surface. Where this is plane it appears to be possible to catch the whole of the reflected light on the mirror or prism of the illuminator, but where the back surface is convex this becomes impossible, and a milky image is very apt to result.

In regard to eye-piece requirements for metallurgical work, these do not appear to differ from those of other microscopical purposes; there is, however, from the user's point of view, a distinct objection

to the use of eye-pieces such as the compensating eye-piece of Zeiss, which can only be used with a particular series of objectives. Unless, therefore, such an arrangement is really essential to allow the best results to be obtained, it will be very much preferable to have eye-pieces and objectives self-contained and interchangeable, not only with other lenses of the same series, but as nearly as may be universally. It may be desirable to state from the author's practice and experience the most useful focal lengths for objectives and magnifications for eye-pieces. It should perhaps be said that it is not suggested that any rigid standardisation of magnifications should be adopted by metallurgists. While a certain degree of uniformity of practice and especially the avoidance of odd magnifications are no doubt desirable, any attempt to tie down microscopists to a few specified magnifications is eminently undesirable, since the magnification for each subject should be chosen specifically to suit that subject. A range of objectives and eye-pieces is, therefore, in the author's opinion, desirable, which will allow of almost any desired magnifications being obtained in a satisfactory manner, that is, by use of an objective of adequately resolving power and without employing a high eye-piece or an unduly extended camera, where photographs are concerned.

The lenses ordinarily used by the author have focal lengths of:—

$$\left.\begin{array}{r}16\text{ mm.}\\8\text{ mm.}\\4\text{ mm.}\end{array}\right\}\text{dry series.}$$

$$\left.\begin{array}{r}2\text{ mm.}\\3\text{ mm.}\end{array}\right\}\text{oil immersion.}$$

Eye-pieces—×8, ×12, ×18.

These lenses have been used because they have been commercially available in those makes which have in the past produced the finest results. So far as the objectives of the dry series are concerned, the focal lengths stated fulfil all ordinary requirements, although a 4 mm. dry objective is not easy to use and requires a great deal of stopping down of the beam of incident light. For this reason, the author, some time ago, suggested the desirability of an immersion lens of from 5 to 7 mm. focus. This would have the great advantage of affording a greater depth of focus than the 4 mm. dry objective, but it might prove difficult to use in a horizontal position unless a special device were provided for holding the oil in place.

With regard to the immersion objectives, that which has given the finest results for the highest magnifications in the author's practice, has been a lens of 3 mm. focus with N.A. 1.40. Unfortunately, these lenses are very delicate in use, and require not only protection from mechanical injury, but also from any agency which affects the cement with which the front lens is attached to the mount and from prolonged exposure to contact with immersion oil. If the latter is not of precisely the right quality, this is alone sufficient to do damage. If this oil is wiped away very gently with a soft cloth and the surface of the lens is then wiped lightly with an old handkerchief slightly moistened with benzol, damage to the cement may be avoided for a long time.

Beyond the objectives named above, a demand exists, and is becoming increasingly important, as indicated above, for first-class objectives of long focus. The author would welcome such objectives having focal lengths of 30 mm., 50 mm. and 75 mm., suitable mainly for photographic purposes. It would, however, be an advantage if they could be designed to work with a low power eye-piece so that they could also be used for visual work

The accessories required in metallurgical microscopy are of some importance. A satisfactory illuminant is essential to all good work of this kind. For visual purposes, the requirements are easily met,

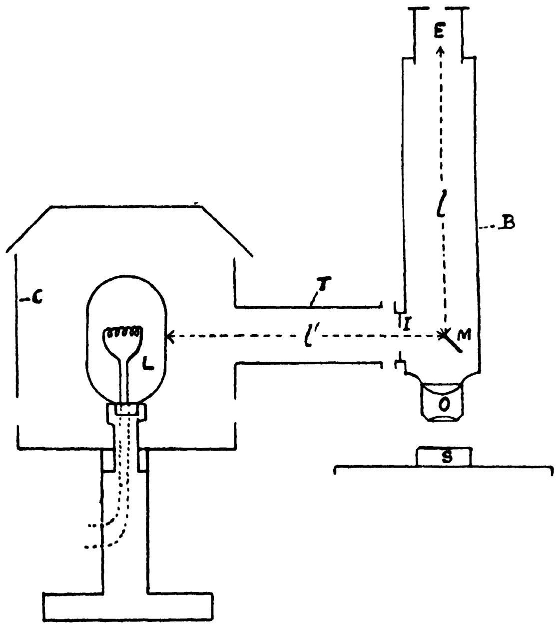


FIG. 1.

since it is only necessary to place opposite to the lateral aperture of the illuminator an uniform source of light having a reasonable area (about 2 centimetres in diameter). Such a source of light may be obtained by placing a suitable burner or electric lamp behind either very finely ground glass or a thin piece of opal shade. If the luminous surface thus produced is placed to one side of the microscope in such a position that its distance from the illuminator mirror is equal to the distance from that mirror to the back focus of the objective, the result is an approach to the conditions of "critical illumination," and for visual purposes these are certainly the best conditions obtainable. This arrangement has the further advantage that no lenses, condensers, etc., are required, and that an iris diaphragm placed just outside the illuminator aperture is all that is needed to regulate the illumination. The whole arrangement can be very simply made by mounting the lamp with a short external tube through which the light passes to the illuminator, the rest of

the lamp being enclosed in a light, tight, but suitably ventilated, case. If the lateral tube through which the light passes is made of the right length, all that is necessary for setting up the illuminating arrangement is to switch on the lamp and to place the small tube almost but not quite in contact with the rim of the iris diaphragm outside the illuminator. A diagrammatic section of this whole arrangement is given in Fig. 1, and a photograph is shown in Fig. 2.

For photographic purposes, the intensity of the illumination obtainable in this way is not large enough to be convenient. The author has endeavoured to use one of the small tungsten arc-lamps known as "Pointolite," as the source for critical illumination in photography, by placing the lamp itself in the conjugate focus position. But with the largest size of this type of lamp at present available, the illuminated area is not large enough. It is to be hoped, however, that a larger form of this lamp may become available, and in that case it will be possible to carry out the best kind of micrographic work without the use of a system of condensers, such as are employed at present.

The arrangements for fine focussing of the microscope when used for photographic purposes frequently present imperfections which are annoying in use, and are liable to lead to the loss of photographic material. Whether gearing or a cord serving as a belt are employed, there is always apt to be some degree of lateral pull applied to the microscope when the fine adjustment head is turned by the operator working from the screen end of the camera. The author has devised a very simple means of avoiding this difficulty and of leaving the microscope free as soon as the operator's touch is removed from the focussing rod. For this purpose, the focussing rod, extending along the length of the camera, operates by means of a small belt, a rotating spindle attached to an independent bearing carries on a separate stand. This rotating spindle is so placed as to be axial with the fine adjustment of the microscope, in whatever position this may be situated. The end of the spindle nearest the microscope merely carries a cross-piece consisting of a thin rod. Fixed to the fine adjustment head of the microscope itself is a light tube of brass or aluminium. In this tube are two longitudinal slots diametrically opposite one another. The independent spindle above mentioned runs down the axis of this tube, but the transverse rod has its ends projecting through the slots of the tube, the slots being made a little wider than the diameter of the rod. If now the spindle is rotated by the operator turning the focussing handle, no pull whatever is placed upon the fine adjustment of the microscope—the motion of the spindle being transmitted to the fine adjustment through the slots in the tube. In these circumstances, a pure turning moment or torque is applied to the fine adjustment, so that there is no tendency to displace the microscope. Further, if the belt connecting the focussing handle to the moving spindle is slightly elastic, the moment the pressure of the operator's hand is removed from the focussing handle, the spindle and the transverse rod which it carries will spring back by a very small amount. In this way, the rod is brought out of contact with the tube, and the microscope is left entirely free from contact with the focussing gear.

If the fine adjustment of the microscope is of the ordinary type in which the head has only a very small longitudinal motion, the tube, slots, and spindle mentioned above also need only be very short. On the other hand, in the type of microscope designed by the author, in which the fine adjustment may be moved through considerable distance by the coarse focussing of the stage, the tube, slots, and spindle must have a length of several inches. This focussing device, which is somewhat difficult to describe in words, is very simple and efficient in action. It is illustrated in the photograph, Fig. 3.

Finally, reference may be made to another matter which sometimes gives difficulty in metallurgical microscopy. This is the mounting of specimens with their surfaces accurately at right angles to the optic axis of the microscope. Mechanical levelling devices of various kinds have proved more or less successful, but they all have the serious disadvantage that the carefully prepared surface of the specimen must be placed in contact with some part of the apparatus, and when this is done there is considerable risk of damaging the surface. The author, therefore, has devised an optical levelling appliance in which the surface of the specimen is utilised as a reflector. The specimen is approximately mounted on a glass slip by means of plasticine, wax or other soft substance. It is then placed under the instrument, and its position is adjusted with the fingers until the reflection is seen opposite a cross-wire. When this position has been obtained, the specimen is accurately level, and the manipulation is so easy that it rarely occupies more than five seconds. A more detailed description of this device has been given in the author's paper on "Some Appliances for Metallographic Research."*

* Journ. Institute of Metals, 1915, I.

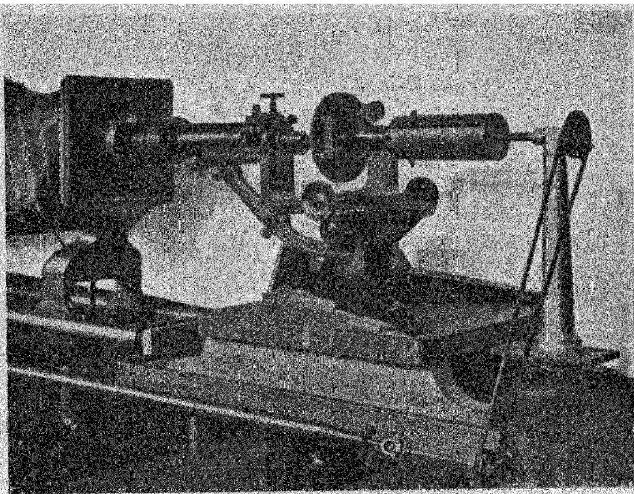


Fig. 2.
Independent Focussing Device applied to Metallurgical Microscope as used for Photography.

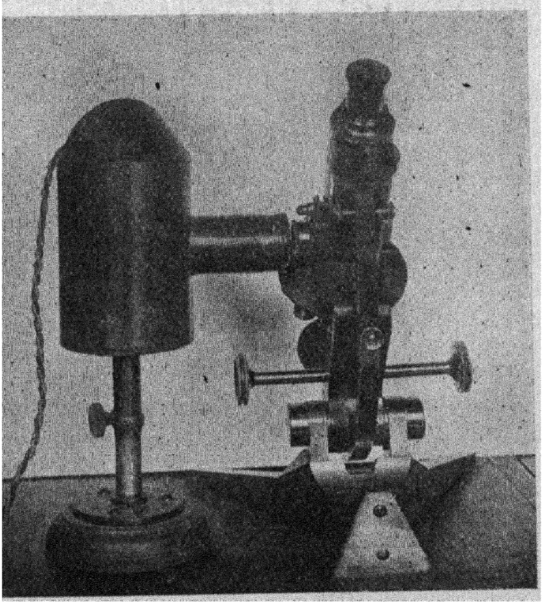


Fig. 3.

NOTES ON THE CONSTRUCTION AND DESIGN OF METALLURGICAL MICROSCOPES.

By Prof. Cecil H. Desch, Glasgow.

The use of the microscope in the examination of metals, first introduced by Sorby more than 50 years ago, has become so widespread that a microscope is now an indispensable item in the equipment of a metallurgical works, whilst the recognition of its importance to engineering works and other places in which metals are employed for constructional purposes is rapidly extending. It is therefore essential to the conduct of these industries that instruments should be available which will allow of the rapid and convenient examination of such metals as present themselves in the course of routine testing, whilst it is obviously desirable that elaborate and detailed investigation of specimens of special interest should be possible. It is quite true that any ordinary microscope of good construction may be used for metallographic work, provided that the higher power objectives are duly corrected for uncovered objects, but the increased convenience of a properly designed instrument is so great as to justify its use, even for routine work. There are now many patterns of metallurgical microscopes on the market, and the following remarks are based on an experience of some 12 or 13 types of instrument, and the examination of the details of many others. The writer has been reluctantly forced to the conclusion that, in spite of many excellent features in some of the British microscopes, the German instruments have proved better in use, and that their superiority is more marked, the longer the microscopes are used. The British designs are often good, and the workmanship, so far as the cutting of racks and screw-threads, etc., is concerned, is often quite satisfactory, but in the course of prolonged use the mechanical arrangements show defects, racks and screws becoming loose, and the accurate focussing of high power objectives becoming troublesome, to an extent which is not met with in the German microscopes. The cause of this looseness after use appears to be insufficient attention to the quality of the metal employed in construction. A rack cut in soft brass, however accurate at first, becomes loose through wear, and no compensation by means of adjusting screws can be quite satisfactory. The fact that such screws are provided seems to be a confession of weakness, since the writer has used a Zeiss microscope, without such screws, for years continuously without any sign of play in the mechanical movements. Racks should be cut in hard, incorrodible metals or alloys instead of in soft brass, whilst the pinions might also be of much harder metal than is usually the case. It is probable that manufacturers have been too much guided by tradition in the choice of the metals to be used in the construction of scientific instruments, witness the tendency, only now disappearing, to use highly polished brass for heavy portions where cast iron would serve the purpose equally well.

The principal parts of the metallurgical microscope may now be considered in succession.

(a) *The Stand.*—There is no reason why the shape of the medical or biological microscope should be slavishly copied in the construction of metallurgical instruments, whilst there are many reasons for choosing a different form, especially when there is a possibility of large specimens being examined. The tripod form of foot, so convenient in work by transmitted light, is awkwardly in the way when examining metals and having occasion to use the rackwork movement for raising and lowering the stage. The Jackson foot is better, and a heavy horseshoe foot still better, as heavy specimens, such as rail sections, may be laid on it for examination under low powers. This is further facilitated by making the bracket which holds the stage capable of swinging to one side, and leaving a clear space between the objective and the heavy horseshoe foot, as in the old vertical Reichert microscope. Special forms of foot, as in the Beck-Rosenhain microscope, have the advantage of great rigidity in both the vertical and horizontal positions. This stand is the most rigid of those examined. The design of Sauveur's universal Metalloscope is also unconventional, and appears to be good, but the writer has no actual experience of it. For photographic work the form adopted in the Zeiss-Martens instrument and in Watson's horizontal microscope is both convenient and steady.

The inverted stand, due to Le Chatelier, has been copied by several makers, but the construction is apt to be flimsy, and the writer has found great difficulty in moving even small specimens on the stage without altering the focus, the light arms which support the optical parts being liable to whip. This could perhaps be overcome by better engineering design, and the type is certainly preferred in some works on account of the rapidity with which specimens can be inserted and examined. The optical conditions of this form are discussed below. It is probable that for the larger instruments to be used for photography the ordinary type of stand might be departed from entirely, and an arrangement modelled on the optical bench adopted, the various optical parts and specimen carriers being supported in such a way as to move freely along a heavy bar of geometrical form to preserve alignment.

(b) *Coarse Adjustment.*—The rack and pinion should be geometrically cut in metal of sufficient hardness to withstand prolonged usage without working loose. The improvement in the methods of gear cutting in engineering practice has been so great in recent years that much would be gained by adopting the methods of marine engineering shops in the instrument maker's workshop. In large instruments, the length of travel might well be greater than at present, so as to allow of a wide range of objectives, and stops should be provided at the ends of the rack to prevent over-

racking. This is particularly desirable in students' microscopes, as it would prevent a common accident in laboratories where inexperienced students use the instruments.

(c) *Fine Adjustment.*—This does not call for much remark, as there are several good forms in use. The speed is sometimes made too great for comfortable focussing of high powers. The side arrangement of small milled heads is perhaps the most convenient.

(d) *Body Tube.*—This should be of the short Continental form, and preferably of wide diameter. The latter condition is essential in instruments to be used for photographic work, and should always be adopted, but it has also great advantages for visual observation, and can be introduced without interfering with the general design.

(e) *The Stage.*—A plain stage of fairly large size is suitable for most ordinary work. It should be provided with a rack-work focussing movement, but a fine adjustment is unnecessary. A central hole, sufficiently large to allow an objective to pass through it, allows of the examination of heavy specimens resting on the foot, unless the support of the stage be arranged to swing aside entirely, as mentioned above. Levelling stages are a nuisance, and should never be used. The specimen should always be levelled before placing on the stage, either by means of plasticine and one of the usual mounting devices, or by means of Dr. Rosenhain's auto-collimating instrument. Mechanical movements to the stage are essential for high power work, and rotation is also a very great convenience, but when both are provided the rotation should be concentric. A rotating plate which is carried by the traversing movements is useless. When a microscope is intended to be used in the horizontal position, it is desirable to provide the mechanical movements with clamping screws, as otherwise a heavy specimen may cause a gradual downward slip during the exposure of a photograph, pulling down the rackwork by its own weight. This has often been noticed when photographing at high magnifications. The rotating circle should have a clamping screw. The Zeiss-Martens stand has a very convenient rotating and traversing stage, but the range of movement is too limited.

The examination of fractures, large crystals in ingot sections, and other things requiring very low powers and great distances, is troublesome when an ordinary microscope is used, and it is often preferable to employ a camera with a landscape or copying lens instead of a microscope. The telephoto attachment of the Davidson microscope gives good results in this kind of work, and the arrangement in the recent pattern, by which the object is carried on a separate stand, movable along a base board, is convenient. On the other hand, the writer does not approve

of the "super-microscope" arrangement, by which the image formed by one objective is magnified by a second objective.

(f) *The Vertical Illuminator.*—Whilst the prism form has the advantage for visual work of causing much less loss of light than the transparent plate, it is unsuitable for high powers, on account of the fact that it only uses one-half of the aperture of the objective, and is consequently liable to produce false images of fine structures. The same objection applies to silvered half-discs or other similar devices. The Beck or transparent illuminator is the only suitable form for photographic work at any but low magnifications. The mistake is very commonly made of fitting a small cover glass, which only imperfectly covers the back lens of the objective, into such illuminators. A plate of larger size should be used. Moreover, cover glasses are not accurately flat, and have no advantage except cheapness and thinness. A large, optically worked plate is used in the Conrady-Watson illuminator and in the Jackson and Blount microscope. The writer has found the thin, square plates used for counting blood corpuscles very suitable, being sufficiently flat and so thin as not to produce doubling of the image. The plate should be capable of at least partial rotation, and should have a sufficiently large milled head to allow of delicate adjustment. Vertical illuminators often leave much to be desired in regard to mechanical construction.

The inverted or Le Chatelier type of microscope calls for a different form of illuminator. As usually constructed, the numerous reflections required tend to injure the definition of the image and to cause loss of light. To a great extent this might be obviated by better optical workmanship, the prism being made in one piece with accurately ground faces, as in the modern range finder. The possibilities of new optical arrangements for illumination are not exhausted.

(g) *The Objectives.*—It is now generally agreed that short mounts are to be preferred for metallographic objectives. A high numerical aperture is necessary for the highest powers. Apochromats are usually recommended for the medium and high powers, but such objectives are commonly deficient in flatness of field, a very desirable quality in metallographic work, and it may be questioned whether good achromats, giving flat fields, are not to be preferred for photographic purposes. It is usual to insert a colour screen when making such photographs, and now that screens which transmit so narrow a band of the spectrum that they may be regarded as practically monochromatic are obtainable, it seems of less importance that the colour correction of the objectives should be perfect. Oil immersion objectives are, of course, necessary for the highest magnifications.

(h) *Eye-pieces.*—These give the least trouble of all the parts of the microscope, the quality being usually satisfactory. Projection eye-pieces are to be preferred for photographic work.

These few notes are presented by way of suggestions for discussion. Each worker will have formed some opinion on the points mentioned, and a comparison of such opinions may be of assistance to manufacturers in determining the design of their future instruments. There is a large demand for metallographic microscopes at present, whilst the supply is very limited, and the time seems appropriate for a consideration of the question whether improvements might not be made in the light of experience.

SOME NOTES ON THE METALLURGICAL PHOTOMICROSCOPE.

By J. H. G. Monypenny.
(Chief of the Research Laboratory, Brown Bayley's Steel Works, Ltd.)

The technique of the photomicrography of metals has advanced very much during the last ten or twenty years, but there are still very marked evidences that many who take up microscopic work in connection with metallurgy appear to study the microscope itself either not at all or only to a very small extent. The consequence is that statements are made about the structures of various metals which are not correct; the presence in sections of minute particles or membranes of constituents other than those stated to be there has been missed simply because the operator did not know how to use his microscope properly. Again, photographs are published which have only a slight resemblance to the structures photographed, in some cases the definition is so bad that the reproductions are not worth the paper they are printed upon. One has only to look through the Journals of, for example, the Iron and Steel Institute to see how true this is.

Even when a metallurgist has devoted a considerable time to the study of the microscope, mistakes may arise in the interpretation of structures. For example, it has been stated that iron carbide (cementite) is not attacked by sodium picrate when its thickness is less than 0.001 mm. (this statement is repeated in one of the most recently published treatises on metallography). This is quite incorrect. Not only are the carbide laminae of pearlite attacked when considerably thinner than this (certainly not more than one-tenth of the thickness mentioned), but also the minute granules in sorbite, produced on tempering hardened steel at about 600° C. Possibly the reason the above misstatement was originally made was either that the aperture of the objective used was not sufficiently high or that the resolving power was much reduced by the use of a prism illuminator or both.

In the following pages the author has attempted to set out some of the conditions which appear to him to be necessary to secure good photomicrographs of metals and the means he has devised from time to time to fulfil these conditions.

(a) *The Illuminant and Condensing System.*—Few who have had any experience in photomicrography will disagree with the statement that the illumination of the specimen is of fundamental importance in the production of a good photomicrograph. Good illumination should comply with the four following conditions:—

(1) The whole surface which is required to be reproduced should be evenly illuminated.

(2) The lighting should be such that the whole aperture of the objective may be utilised.

(3) The wave-length of the light used should be that for which the objective is corrected.

(4) The wave-length of the light used should be suitable to the colour of the specimen.

Fortunately, in most metallurgical work the specimens rarely call for the use of any definite colour of light, and hence the necessity for complying with condition No. 4 does not, in general, arise. This is a great advantage, as it enables one to adjust the colour of the light to fulfil condition (3). In other branches of microscopic work (*e.g.*, in connection with Biology), it may easily occur that the requirements under conditions (3) and (4) are opposite, and then the photomicrographer has either to use a colour for which the objective is not adequately corrected or which is not best suited to the specimen.

In metallurgical work the objective acts as condenser, and it is well known that to produce " critical illumination " the illuminant should be focussed on the section, and should therefore occupy the

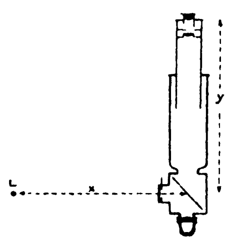


FIG. 1.

Diagram showing conditions for critical illumination.

position L shown in Fig. 1, so that the distances x and y are equal. Practically it is found that the illuminant may be to some extent out of focus without producing any bad effect, providing the objective transmits a full solid cone of light. This may be judged by looking at the back lens of the objective after removing the eye-piece, when (the iris on the vertical illuminator being open) the back lens will be full of light and evenly bright if critical illumination has been obtained. The fact that the illuminant may be to some extent out of focus is of great value in allowing one to get rid of the effect of small surface markings on the illuminant itself.

Placing the illuminant in such a position has obvious disadvantages, *e.g.*, it would be inconveniently close to the microscope and the heating effect produced on the latter would be considerable. Again, to illuminate the whole visible field in the microscope, the illuminant would have to have an evenly bright area at least as large as the diaphragm of the ocular in use (say 7 to 8 mm.), obviously, therefore, illuminants of small area (*e.g.*, Nernst or Arc lamps) could not be used in this way.

As regards the illuminant, the author prefers the 500 C.P. Pointolite Lamp (a tungsten arc lamp made by the Ediswan Co.) to any other type of lamp made; the intensity of the light is very great, and it is absolutely steady. It requires direct current, and where this is available the author has no hesitation whatever in recommending it in preference to any other form of illuminant. Previous to this lamp being on the market (about 1917), the author had tried a Nernst lamp, an arc lamp, and lime-light, and had for some years used the last in preference to the first two. The intensity of the light given by the lime is not nearly so great as with the arc lamp, but on the other hand it is perfectly steady, and this cannot be said of the arc lamp.

Coming to the condensing system, probably one of the simplest arrangements is that shown in Fig. 2. In this case the condenser C forms an enlarged image of the illuminant L at L_1, the correct distance from the illuminator to give critical illumination as described earlier. By this means the area of the illuminant is spread out, and with, for example, lime-light, one may obtain perfectly even illumination even when photographing at, say, 5 or 6 times the initial power of the objective. The effect of any slight irregularities

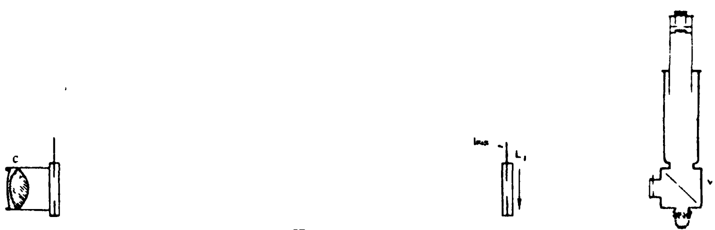


FIG. 2.
Condenser System No. 1.

on the surface of the illuminant may be avoided by forming the image L_1 about 1 in. nearer the microscope than its correct position, as mentioned earlier. It is advisable to have an iris diaphragm at L_1 and to close it until only slightly more than the area to be photographed is illuminated. This cuts off a lot of stray light which would otherwise reduce the contrast by giving a general fog over the whole section. This iris should be focussed fairly accurately on the section, otherwise there is a gradual falling off of the illumination on the edge of the field instead of a sharply defined edge to the illuminated area.

While this method is perfectly satisfactory for use with lime-light —the author has taken several hundred photographs at magnifications ranging from 30 to 2,000, using an arrangement of this description—it has certain drawbacks; for example, a great deal of light is wasted, and with an illuminant of small area it is difficult to fill the field evenly unless a very long optical bench is used.

These defects are obviated in the following arrangement. In this, advantage is taken of the fact that if a biconvex lens is held between the eye and a light (*e.g.*, a candle flame) in such a manner that the eye and flame occupy the position of conjugate foci then the lens itself will appear to the eye as an evenly illuminated disc, and

for the purposes of microscopic work may be looked upon as an illuminant. There is one essential point, however, the beam of light thrown by the lens must cover the whole surface of the back lens of the objective, otherwise some of the aperture of the latter is lost.

In Fig. 3, A represents a lens of about 6 in. focus, placed at the requisite distance from the microscope to give critical illumination, as described earlier; the objective therefore uses this lens as the illuminant, and forms an image of it in the field (if any slight scratches are present on the surface of the lens, it should be moved very slightly out of focus). Condenser B (about 2⅝ in. focus and 2⅛ in. diameter) is placed at such a distance from A that the

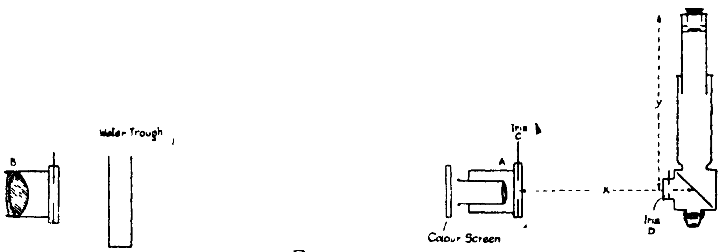


FIG. 3.
Condenser System No. 2.

latter focusses B approximately on the objective. Finally B forms an enlarged image of the illuminant on A. This sounds rather complex, but the result is that if the eye be placed at A, B appears as an even disc of light, and similarly to an eye placed against the objective A appears as an even disc. As mentioned above, the only point that must be carefully watched is that the image of B formed by A on the objective must at least cover the back lens of the latter. The figures given above refer to the author's arrangement, and in this case the image is rather more than two-thirds of an inch diameter, and therefore amply large enough for any objective in use. Condenser A need not be more than 1 in. diameter, but the image of the light formed on this lens by B should completely fill it. This condenser (A) should have an iris diaphragm for limiting the area of the field illuminated as described earlier. An iris is not required on condenser B, except for centering and focussing purposes.

Using this arrangement, one is able to illuminate evenly the section, and also provide critical illumination. It will be found that if condenser A is used without B, unless the illuminant has a large area or is placed very near to A, the conditions of critical illumination are not obtained, the beam of light not being sufficient to fill the back lens of the objective. The effect is equivalent to cutting down the aperture of the objective, with all the bad effects produced thereby. The author has seen more than one metallurgical photomicroscope in use in which this condition of things has obtained.

It is obvious from Fig. 3 that, using an illuminant of small area, such as the Pointolite, condenser B should have a short focus, and also the better corrected it is the more light will be available—the author uses the Watson-Conrady condenser, and finds it excellent

for the purpose. Doubtless other opticians could supply similarly corrected condensers. Condenser A has a longer focus (the actual. focal length will depend on the tube length employed and the distance between the condensers), and as it need only be of small diameter, such a high degree of correction as in B does not seem necessary.

(b) *The Vertical Illuminator.*—The author does not propose to enter into the question of prism *versus* disc illuminator to any great extent. The fact that with high powers a disc illuminator must of necessity give and does give far better definition and much more detail, is evident to anyone who has studied the subject or who has critically compared the two illuminators with the same lens on the same field. Examples of this have been published independently by Rosenhain and by Benedicks; the author (who was unaware of Rosenhain's work) investigated the matter before Benedicks' paper was published, and his results, though not published, were communicated to some of his friends. It is probably not so well known, however, that the results with low power lenses show the same differences, though not in so marked a manner. The differences produced for any given objective depend on the fineness of detail in the section. Other things being equal, the superiority of the disc becomes more marked as the detail to be reproduced becomes finer. The author always uses a disc illuminator even with the lowest powers, except under exceptional circumstances. (Such may arise in a low power photograph of an object showing no fine detail and possessing very little contrast.)

While, however, the author is convinced of the superiority of the disc illuminator, he has found that many individual discs are very poor specimens, and in this respect he would urge on instrument makers the necessity for more care in choosing material for the "disc." In many cases the glass is so thick and so uneven that the definition of even a low power lens in absolutely ruined. The author a few years ago received an illuminator from one of the largest microscope makers in England—he returned it at once with a note that it was useless owing to the bad glass (giving them details of the behaviour of the disc). The illuminator was returned to him with a fresh glass fitted, which was every bit as bad as the first one. The effect of this bad disc is shown in Figs. 4 and 5. These represent the same field taken with the same objective, ocular, plate, and screen, in fact every condition the same, except that in Fig. 4 the disc was a good one, while in Fig. 5 the disc was the bad one mentioned above. It was absolutely impossible to get any sharper definition than that shown in Fig. 5. The author suggests that this is a point to which instrument makers should give far more attention than they do—there is no doubt at all that many of the glasses supplied with disc illuminators are far too thick, and they are often uneven. It is evident also that the discs cannot be very carefully examined by the makers before being put into stock, otherwise such defects would be quickly discovered.

It may be of interest to mention that the bad disc mentioned above had far more effect on the performance of the 1 in. and ½ in. objectives than on the 1-6th, probably owing to the larger area of the glass used by the former lenses. Probably this fact and the

prevalence of unsuitable material for the disc may account for the opinion frequently held that for such low powers the prism illuminator gives the better effect. A prism would give a much better result than Fig. 5.

There are three other points in connection with the vertical illuminator that the author would like to mention.

(1) The illuminator is rarely made large enough to fill the back lenses of the lower power objectives—for example, the 24 mm. N.A. .30 or the 12 mm. N.A. .65. The only disc illuminator known to the author which is large enough for these lenses is the large pattern made by Watsons, London.

(2) The illuminator should be fitted with an iris diaphragm, which should have some type of centering adjustment. This iris is used in the same manner as the iris on a substage condenser, and should therefore close absolutely central with the objective. Such adjusting movements as are found on the Watson pattern mentioned above are suitable.

In connection with the prism illuminator it is curious that in the pattern as ordinarily sold, the iris diaphragm closes concentrically with the middle of the front face of the prism, and therefore with a line about one-eighth of an inch from the centre line of the objective. The iris should, of course, close concentrically with the middle of the bottom edge of the prism, as shown in Fig. 6, where A indicates the centre line of the iris as ordinarily fitted, and B the line on which it should close. The effect, on the performance of an objective of short focal length, of closing the iris about line A can be imagined.

(3) One of the great defects of the disc illuminator, especially with the lower power objectives, is the presence of flare due to the reflection of the incident light by the outer surface of the back combination. This is a matter, however, which could probably be remedied to a great extent by the objective designer. It will be obvious that (other things being equal), the more convex this back surface is, the less the amount of flare, since more of the reflected light will be reflected on to the inner surface of the draw tube (and be absorbed by the blackened surface), and less will reach the eye-piece. The author has one lens in his possession in which the back surface is apparently slightly concave, and, owing to the amount of flare caused thereby, the lens, though a magnificent one from every other point of view (it is the Zeiss 12 mm. Apochromat N.A. .65) is not so valuable metallographically. The author would suggest that this is a point to which opticians could usefully give their attention in computing objectives for metallurgical work.

It is, of course, obvious that with the present method of construction of objectives there is much more likelihood of flare being obtained with apochromatic objectives than with achromatic—especially with the lower powers. In the former the back combination has very little magnifying power, its function being chiefly that of correcting the aberrations and other faults of the front combinations. In the simpler achromatic the back combination frequently has a considerable magnifying power. The more convex back surface of the latter type of lens will therefore cause less flare than the less convex surface of the more highly corrected combination. The author has frequently noticed this difference in

comparing the different types of lenses. Very often the effect of the flare can be overcome by using a combination of plate and developer which gives contrast easily; for example, such methods succeed perfectly with the 24 mm. Zeiss apochromat; with the 12 mm., however, as stated above, the flare is so great that the author uses for preference a very good achromatic lens of the same aperture.

(c) *Colour Screens.*—As mentioned earlier in the paper, the use of colour screens in metallurgical work is simplified very much, as it is only on very rare occasions that a section is obtained which requires light of some definite wave-length in order to get the best results, consequently the whole attention can be given to using the light most suited to the lens.

If the objective is apochromatic, light of any colour may be used, but it is generally advisable to use blue light in preference to green or red (especially with the higher powers), as the resolving power is thereby increased. It is *always* advisable, however, even with the best apochromats, to focus with the same colour light as is used for photographing. The author's general practice in this case is to focus with a blue screen in position (generally the Wratten tricolour blue), and then remove the screen and expose on a non-colour sensitive plate (all blue screens increase the exposure rather considerably). This method is perfectly satisfactory for the Zeiss apochromats, even at the highest magnifications.

With achromatic, or semi-apochromatic lenses, one has not the same freedom. Owing to the simpler construction of these lenses the correction for spherical aberration is taken to a high degree of perfection for light of one colour only (generally yellow green), and the best results are only obtainable by using this colour. The author has examined such objectives made by most of the leading makers in England, and has never met one in which the correction for spherical aberration for blue violet light was sufficiently good (compared with that for green light) to make it worth while taking photographs with such light. Some lenses were certainly better than others, and, curiously enough, some of the lenses which were very poor with blue light worked quite well with red light. The author is of opinion that it would be far better if this fact were more widely acknowledged by the makers. To read the catalogue descriptions of some of the lenses one would imagine that they would perform perfectly without any screen at all. The author has known of cases where objectives by well-known English makers have been purchased and used in the belief that they would perform well under these conditions. After seeing the results the purchaser came to the conclusion that the lenses were very poor specimens. In one case which occurred recently the author was able to convince the purchaser that the type of lens in question would give very fine results if used with a suitable colour screen instead of in the manner suggested by reading the maker's too optimistic description. Probably one of the best screens to use for such lenses is one of the tricolour green type. The author uses the one made by Wratten, along with the Allochrome plate by the same maker. Such a plate as this (sensitive to yellow green) is preferable for this purpose to a panchromatic plate, as the red sensitiveness of the latter is no advantage—rather the reverse.

(d) *The Relationship of Aperture and Magnification.*—With the author's arrangement of condensers, the beam of light entering the vertical illuminator is rather larger than the largest back lens of any objective he has; it is therefore necessary to use the iris diaphragm on the illuminator (D, Fig. 3). His practice is to cut down as little as possible. Generally he leaves the back combination 5-6ths full; it is only on rare occasions that he reduces below this. If the aperture is cut down much more than this, any surface irregularities due to scratches are shown up in a very prominent manner, owing to diffraction bands. For this reason, of course, it is well to reduce the aperture to less than 5-6ths when any relief effects in the structure have to be emphasised. The effect of gradually reducing the aperture of an objective has probably been studied mostly from the point of view of the higher power objectives. The bad effect produced on the images given by such lenses owing to such reduction is probably well known, though the fact that photomicrographs of metals showing diffraction effects caused by such reduction are still published shows that this bad effect is not always sufficiently appreciated. With lower power lenses the effects are not so marked metallurgically, since, generally, the photographs taken with such lenses give a general view over a large field, and are not intended to show fine detail. In addition to this, such low power lenses (*e.g.*, 1 in. or 2-3rds) have in general a higher ratio of N.A. to magnification than the higher powers. For example, the N.A. of the lenses mentioned above is generally between .24 and .30, and they are used for photographs at, say, 50 to 150 diameters. On the other hand, twelfths used at 1,000 and 1,500 diameters have at the most 1.4 N.A., and frequently only 1.2 to 1.3. Consequently there is more latitude with the stopping down of low power lenses, but still it should be remembered that with these lenses diffraction effects are produced, and there is a limit to the reduction of the aperture beyond which it is not advisable to go. By suitable stopping down, however, one can often, with these low powers, obtain a larger field sharp all over—frequently of great importance.

Under present conditions nothing is gained by photographing at any higher magnifications than about 1,500; with the present maximum aperture available (N.A. 1.40), all detail which can be shown is visible at this magnification. Any higher magnification is of the nature of an enlargement, and can be obtained equally as well by photographing at this magnification (× 1,500), and enlarging from the negative, as by taking the negative direct at the higher magnification. There is no doubt that for many metallurgical purposes a higher magnification, coupled with greater resolving power, would be of great value. This could be obtained either by using light of very short wave-length, with its attendant difficulties of focussing, and also the necessity of special lenses capable of transmitting light of such short wave-length or by increasing the aperture of the objective. With regard to the latter, the author believes the firm of Zeiss produced some years ago a 2.5 mm. objective working at about N.A. 1.65. This objective had a front of flint glass, and used as immersion fluid monobromide of naphthaline. Its use, however, for transparent work was attended with great difficulties and expense, inasmuch as the slip and cover glass had

to be of flint glass. With metallurgical work, however, these difficulties would not occur, and it seems to the author that such a lens would be of value in elucidating some of the finer structures met with in metals. If such a lens could be made it should preferably be apochromatic, but, if not, it might be advisable to correct it for blue violet, as the "preferred colour," in order that the highest resolving power could be obtained photographically.

It is obvious that at the highest powers the apochromatic lens has a much greater resolving power than the semi-apochromatic of the same aperture, owing to its capability of working with blue violet light. It should be emphasised that, other things being equal, using light of wave-length 4,500 A.U. instead of 5,500 A.U. is equivalent in its effects to increasing the N.A. approximately 25 per cent.

(e) *Exposure and Vibration Effects.*—In metallurgical photomicroscopes for use in works' laboratories it is very important that the exposure required, especially with high magnifications, should be as short as possible in order to avoid the effects of unavoidable vibrations. For such purposes an intense illuminant is required, and such lamps evolve a very considerable amount of heat, which may easily cause trouble with the cement used in the various combinations of the objective. It is very necessary in such cases that an adequate cooling trough be placed in the beam of light before it reaches the microscope. The heat evolved also causes trouble owing to the expansion effects produced in different parts of the microscope and camera.

Even when the exposures are comparatively short (*e.g.*, a few seconds), they still give plenty of time in the case of the higher powers for vibration to have considerable effect. The author has, however, been able to overcome this completely by swinging the whole photomicroscope on springs, as shown in Fig. 7. It will be noticed that the author's camera is vertical. This position has several advantages from a works' point of view; obviously it occupies less floor space than the horizontal pattern, and is probably more easily swung than the latter. It may be mentioned that, with the suspension system used, photographs at 1,000 and 1,500 diameters were successfully taken, although the laboratory was within 50 yards of four 8-ton steam hammers, and also adjoined three sets of railway lines running into the works.

(f) *Low Power Photography.*—It is frequently desirable to be able to reproduce at low magnifications fairly large areas under vertical illumination. With ordinary low power objectives (*e.g.*, 2 in. or 3 in.), it is possible to take photographs at, say, 20 or 30 diameters, but in general the field is only small, about $\frac{1}{8}$ in. or $\frac{1}{10}$ in. diameter. If attempts are made to get a larger field, trouble is at once experienced with the illumination, and often with the definition falling off. Frequently a very large field is required if the photograph is to serve its purpose, as, for example, with groups of flaws, very coarse structures, and segregated areas.

Some ten or twelve years ago the author devised an arrangement for this purpose, and as he has found it exceedingly useful, he puts it forward in the hope that it may be of use to others. There is nothing really novel in the method, it is a combination of several

ideas, but so far as the author is aware, such an arrangement has not been described before, nor has he heard of any similar apparatus.

For such work the ordinary low power objective is not suitable—its "field" is not big enough. The lens the author uses is the 35 mm. projection lens made by Zeiss, though probably equally good results could be obtained with some of the very short focus photographic lenses made by various opticians. As illuminator he uses a piece of microscopic cover glass $1\frac{7}{8}$ in. × $1\frac{1}{4}$ in., mounted in a light brass frame which fits on to the objective. The frame is pivoted, allowing the illumination to be adjusted to a nicety. This disc is used between the objective and the section.

If one is using an enlarging lantern or a projection lantern, then, in order to get satisfactory lighting, as is well known, the condenser must be close to the negative or slide and must focus the illuminant on the projection lens. The same principle is used for photographing metal sections, and the arrangement of condensers is shown diagrammatically in Fig. 8, which shows the 35 mm. lens A attached to

FIG. 8.

Condenser system for low power photography.

the microscope tube and the section B on the stage (the microscope used is the large "Works" model made by Watsons, London, which has a very wide tube—the inner draw tubes are removed for use with this lens). The condenser D forms a considerably enlarged image of the illuminant C (the 500 C.P. Pointolite Lamp) at E close up to the second condenser F, and the latter in turn focusses the image (after reflection at the 45° cover glass reflector G and the surface of the specimen) on the lens A, as indicated roughly by the dotted lines. The condensers used are $2\frac{1}{8}$ in. diameter, and it is possible to illuminate evenly a section about 1 in. diameter; this is more than required, as the field of the lens is only about $\frac{5}{8}$ in. diameter. Fig. 9 shows the apparatus set up, and Figs. 10 and 11 some of the results obtained.

It is obvious that these low powers are of special value where either the structure is very coarse, or where one wishes to show the variation of structure over a fairly large area. For example, Fig. 10 (× 15 diameters) shows far better than a photograph at, say, 100 diameters, the structure of the sample of overheated steel from which it was taken. Fig. 11 (× 15 diameters) illustrates another type of photograph for which the ordinary microscopic objective would be quite useless; this shows the size and distribution of carbon in an unsound segregated area. This actual example is rather unique, showing, as it does, high and low carbon areas in close proximity.

With the author's camera and microscope, magnifications ranging from 9 to 23 can be obtained, but with a longer camera it would be quite possible to reach 30 or 40 diameters. As mentioned above, the tube of the author's microscope is very wide and comparatively short (2 in. diameter and $4\frac{3}{8}$ in. long), and this enables one to use practically the full field of the 35 mm. lens; with a narrower tube, of course, part of the field would be cut off. In such cases one may do without the microscope and mount the lens on a small fitting (with either spiral or rackwork focussing) on the front of the camera. In one or two cases the author has done this, and has succeeded in obtaining a $6\frac{1}{2}$ in. circle at 9 diameters (*i.e.*, a field of .72 in.). The definition in this case was not quite perfect round the edge, but it was sufficiently good for the purpose.

It may not be out of place to mention that when taking a photomicrograph without using an eye-piece it is necessary to avoid reflection from any metallic surface inside the microscope tube. The latter should be coated with a dull black varnish, but it is generally advisable to put in a lining of black cloth. Such a lining

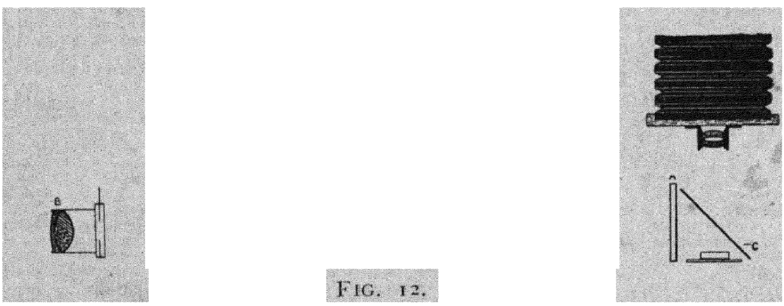


FIG. 12.

Illuminating system for lowest powers (up to about $\times 5$).

can be easily made by gumming a piece of black cloth of the required size on to a similar piece of fairly stiff paper, then rolling into a cylinder (cloth inside), which can be slid into the microscope tube.

For still lower powers one may use a photographic lens of 3 in. to 5 in. focus; the one used by the author is a $5\frac{1}{2}$ in. Holostigmat by Watson, and with this he can reproduce from natural size up to about 4 diameters. In this case a different system of illumination is employed. For the 45° reflector a thin lantern slide cover glass is used. (It is possible to obtain thin microscopic cover glasses in sizes up to $4\frac{1}{4}$ in. $\times$ $3\frac{1}{4}$ in., but such glasses are very fragile.) A large piece of ground glass is mounted close to the section as shown at A in Fig. 12, and the condenser B throws a parallel or slightly divergent beam of light on this. The idea is to produce an evenly illuminated disc of light on the ground glass, and the light from this is reflected on to the section by the 45° reflector C. Such low magnifications are especially valuable with sections etched with one of the "copper" reagents (such as Stead's, Rosenhain's, or Le Chatelier's), which require a low magnification as a general rule. Fig. 13 is an example of this—it represents a section ($\times$ 4 diameters) from a small sample ingot (taken for analytical purposes from an

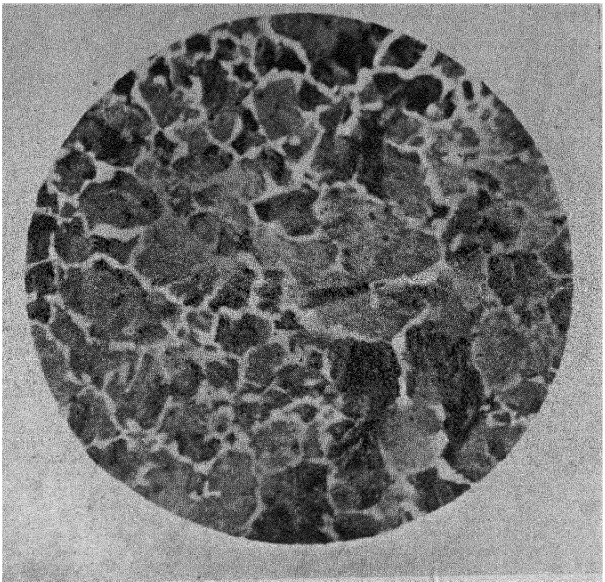


FIG. 4.
Ferrite and Pear'ite, using good disc.
× 100.

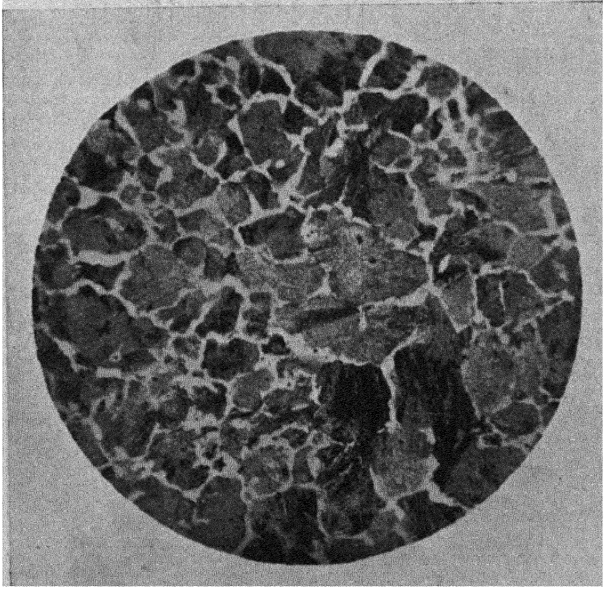


FIG. 5.
Same field as No. 4, but taken with bad disc. × 100.

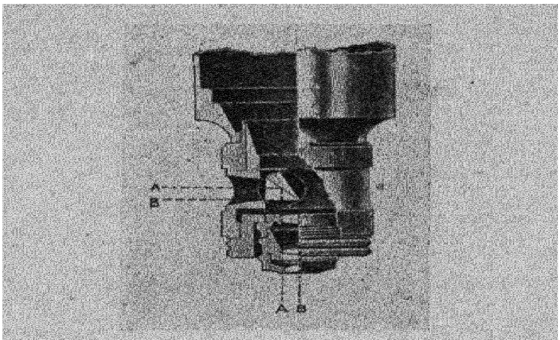


FIG. 6.

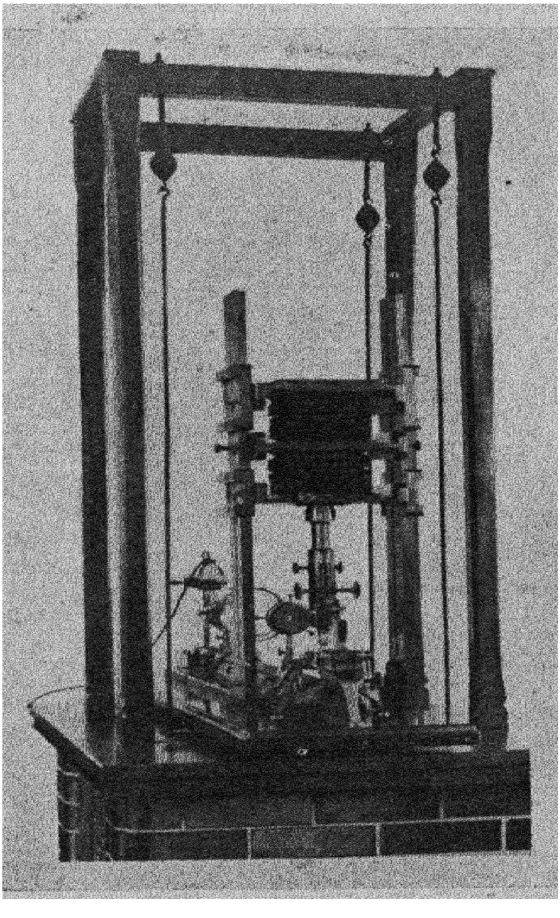


FIG. 7.

Photomicroscope showing spring suspension.

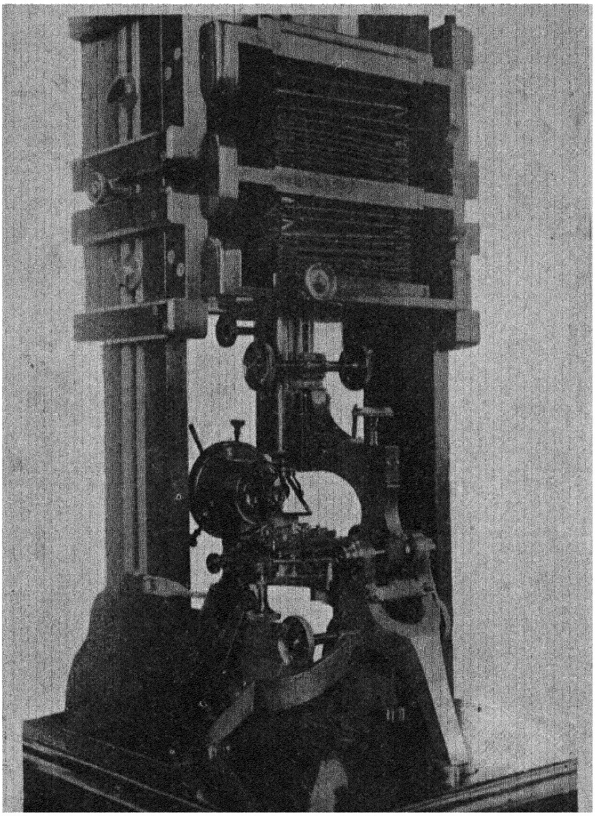


FIG. 9.

Microscope and condenser arranged for low power photography

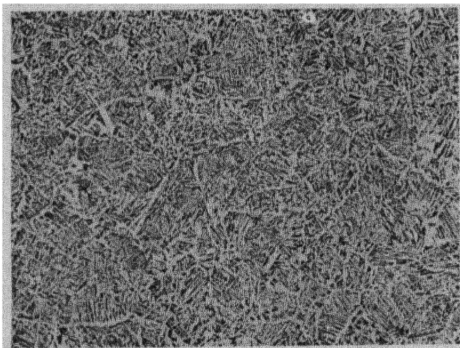


FIG. 10.
Overheated Mild Steel, × 15 diam.
(Reproduced half size—*i.e.*, × 7½ diam.)

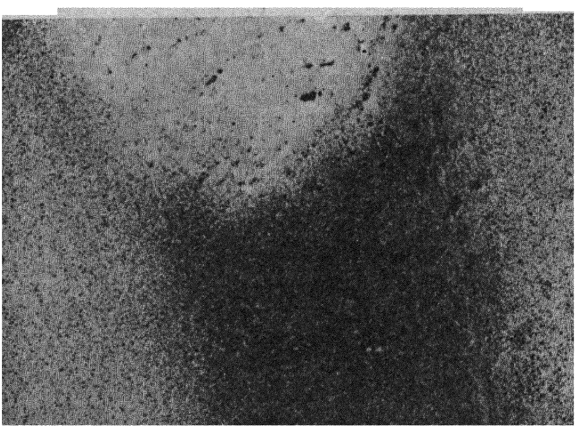


FIG. 11.
Segregated Core in Mild Steel Bar × 15 diam.
(Reproduced half size—*i.e.*, × 7½ diam.)

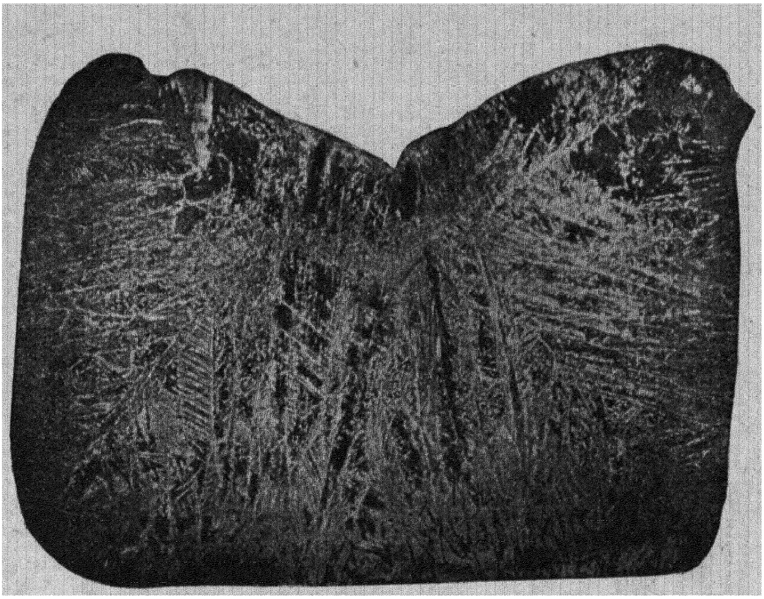


FIG. 13.

Chill crystals in small steel ingot (etched cupr'c reagent), × 4.

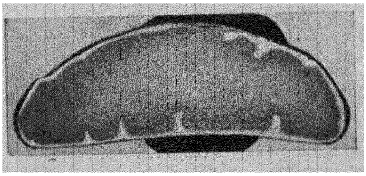
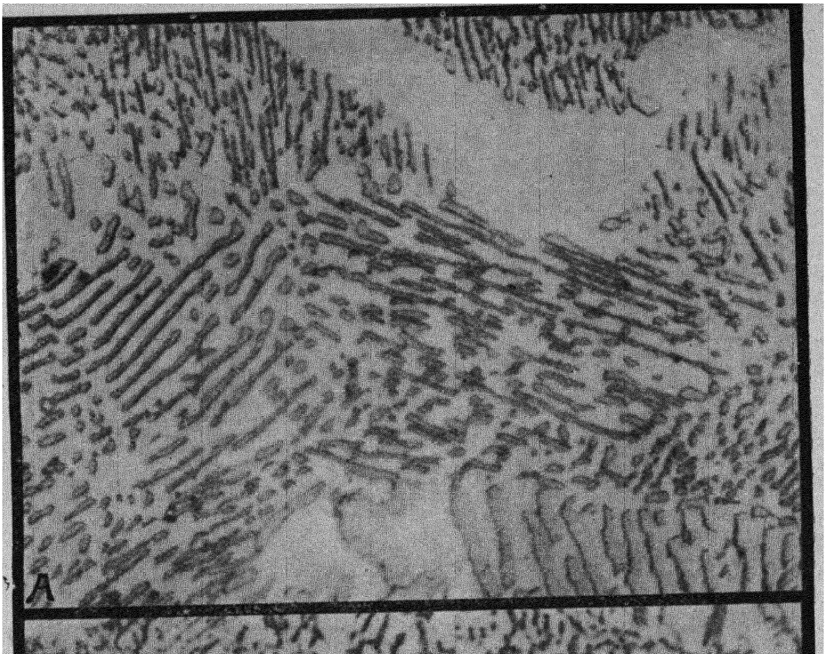


FIG. 14.

Section of Burnt File Blank showing decarburisation, × 3.
(Reproduced half size).



A.—Laminated Pearlite and Ferrite.—× 3,500 reduced to 3,000 Zeiss 2 m/m. apochromat. N.A. 1.4., nonochromatic blue light. (Negative × 1,000 and enlarged.)

B.—Pearlite (finer than A) and Ferrite.—× 3,500 reduced to 3,000. Watson 2 m/m. "Holos" N.A. 1.35, yellow green light. (Negative × 1,400 and enlarged.)

electric furnace), and shows the development of long chill crystals. Fig. 14 (from a file blank burnt in forging) was also taken by this method, and shows (× 3 diameters) the decarburisation formed both in the skin and round the cracks.

A method of illumination similar to the last one was described by F. B. Foley in "Metallurgical and Chemical Engineering" (August 1st, 1919). He used it for low power photomicrographs (at about 7 diameters). For this purpose, however, the author prefers the arrangement shown in Fig. 8, as it gives better detail at these magnifications.

In conclusion, the author wishes to thank the Directors of Messrs. Brown Bayley's Steel Works, Ltd. (and in particular Mr. H. Brearley) for permission to publish the photographs accompanying this paper, and also to Messrs. F. S. and W. H. Nicholds (members of the Laboratory Staff) for their assistance in preparing the photographs and diagrams.

METALLURGICAL MICROSCOPES AND THEIR DEVELOPMENT.

By LESLIE AITCHISON, D. Met., B.Sc., A.I.C., and F. ATKINSON.

It is assumed that the primary function of this symposium is to bring out the present position in regard to microscopes and also to elicit those improvements which could well be introduced into microscopes with a view to improving the instruments, making them more convenient to employ, and also elaborating the uses to which they can be put. The present notes are written from the point of view of the metallurgist, and primarily from that of the working metallurgist, to whom the microscope is of constant value and usefulness. No attempt is made to discuss the questions from the optician's standpoint, but rather to indicate the needs of the metallurgist in the hopes that the optician and miscroscope manufacturer will be able to meet more and more of these requirements.

In saying anything of modern microscopes it is difficult to avoid constant reference to the products of the Continental makers, and to make comparisons between their microscopes and those produced in this country. This has reached the stage at which comparisons usually take the form of stating how near the British article approaches to the Continental. The position will not be really satisfactory until the reverse of this position is the true one, i.e., until the British article is compared with the Continental on the basis of the superiority of the former and not upon its inferiority.

Speaking as users of microscopes and microscopic outfits, one of the first points that requires attention is the more prompt incorporation in the instrument of those details and fittings which make the use of a microscope less laborious. The Continental makers were always ready to adopt and to incorporate these details, and it would be of great assistance if the British manufacturers would do the same. For instance, the Continental makers would supply a stage micrometer in metal (a great improvement upon those made in glass), marked in tenths and hundredths of a millimetre. The British manufacturer has up to the present given us one marked only in tenths of a millimetre.

A similar matter, and one that causes a good deal of trouble, is the lack, upon photomicrographic outfits, of a really good, reliable and workable fine focussing arrangement which can be operated from the camera end. This objection applies to *all* microphotographic outfits, British and Continental, as none of those made give real satisfaction. For metallurgical work photomicrography is of great importance, and if photographs are to be taken at high powers, *e.g.*, up to 1,000 diameters, the focussing apparatus is of vital importance. Those at present manufactured do not work really well, and cause a great deal of irritation to the operator.

Connected with the photomicrographic outfit is the trouble which is experienced because of the lack of adequate devices for the prevention of vibration of the apparatus. The greatest proportion of metallurgical photomicrography has to be done in works. Such places are always subject to a fair amount of vibration, which is usually transmitted in a greater or less degree to the apparatus. This almost renders high power photography of the higher order impossible. The problem of vibration is not new, and various efforts have been made to solve it by the makers, but up to the present these efforts have not proved at all successful. The existence of the vibration is one of the factors which limits the development of higher powers in industrial microphotography.

Photomicrography is not possible at all unless the source of light is good and reliable. The arc lamp is not good for photography. It is too uncertain. It is very prone to flicker, and also to give a wandering source. Further than that, it requires a good deal of attention—replacing and adjusting of carbons—whilst it also usually involves the use of a mechanical device for keeping the arc in its correct situation. Lime-light does not suffer from these defects, but it presents the other difficulty, namely, that it is not sufficiently intense to provide a good illumination at high powers, and therefore to allow of short exposures. The specially designed sources of illumination, such as the Pointolite, are distinctly better, and it is considered that this is the form of illumination which will best repay development.

It is obvious, of course, that the improvements indicated above are of little value unless they are accompanied by excellence in the more purely optical parts of the outfit. The critical part of the microscope is undoubtedly the combination of the lenses, and it is probably in this part of the equipment that the standard Continental makes are most missed. There are numerous points about the lenses which could be considered, but one of them can be selected as typical. This is the production of a flat field. In this respect the Continental outfits showed a great superiority, as they permitted photographs to be obtained perfectly sharp at really low magnification (10). This was of immense importance in the study of cast metals and in watching the persistence of the primary crystallisation of a metal through all the subsequent stages of working and treatment. Unfortunately no such good results can be obtained with the usual British lenses.

The usual range of magnification of the modern microscope ends at about 1,500 diameters—particularly in so far as photography is concerned. Unfortunately there are many things which this magnification does not reveal, and which the metallurgist would be glad to investigate. It seems that it might be useful to indicate a few of the points which the invention of a " metallurgical ultra-microscope " might be expected to make plain.

Several such points arise in connection with tempered steel, and although it is not possible to make their significance entirely plain without introducing a good deal of matter apart from microscopical, they may be taken as typical problems. As is well known, hardened steel consists essentially of a solid solution of iron carbide in iron. If this solution be tempered, a certain change takes place in it, which is reflected in the mechanical properties of the steel, which becomes softer and tougher. This change is usually (and probably quite correctly)

ascribed to the splitting up of the solid solution, the iron carbide being precipitated in a fine state of division throughout the solvent iron. That this explanation is correct in its outline is more than probable, and when the tempering has proceeded to something like completion the presence of the carbide is easily detected. The early stages of the decomposition are practically incapable of observation with the present microscopic means which are available, but this is the portion of the process which is of the greatest interest and importance. It is almost impossible at the present time to say at what temperature the decomposition of the solid solution commences or how it proceeds. In many carbon steels the maximum stress, which in the ordinary way is supposed to decrease when the tempering temperature increases, actually increases at tempering temperatures near to 400° C. Typical results are:—

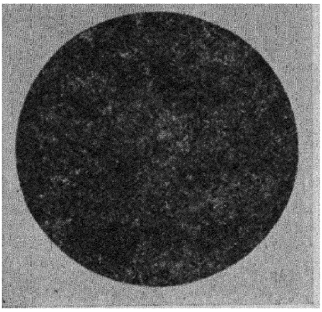
TABLE I.

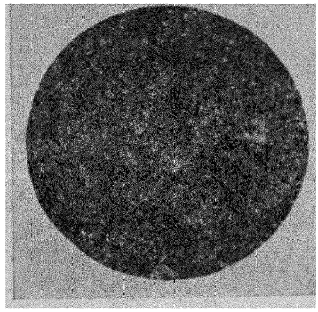
Steel	Heat Treatment		Max. Stress tons/sq. inch
0.3%	Quenched 850°C	temp. 15°C.	50 5
carbon	,, ,,	,, 100°C.	49 6
	,, ,,	,, 200°C.	49 4
	,, ,,	,, 300°C.	47.1
	,, ,,	,, 400°C.	50 1
	,, ,,	,, 500°C.	46.8

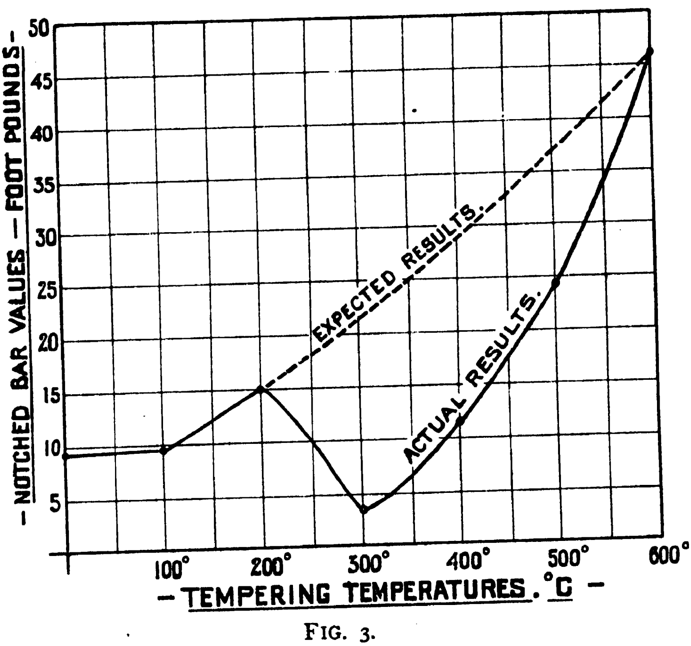
It is quite likely that if the constitutional changes going on within the steel could be examined microscopically, and a better idea of these changes formulated, the explanation of the peculiar happenings would be found. This would require a very high power—something probably of the order of ten times as great as the present powers.

Similiar problems arise in connection with the tempering of the alloy steels. In the nickel chromium steels, for instance, a property known as temper brittleness is shown by steels which cool slowly from or through a certain range of temperature, *e.g.*, 425° C. to 550° C. In all other respects the mechanical properties of the steels are the same whether cooled quickly or slowly. The effect of different methods of cooling from this temperature upon the toughness is shown in Table 2.

It is inconceivable that there is no difference at all in the constitution of the two steels, but the present microscopic methods fail entirely to detect the difference (see Figs. 1 and 2). It is possible that higher powers would make the detection possible. The same powers might also give an explanation of the peculiar impact values which are obtained from the alloy steels by tempering at comparatively low temperature, *e.g.*, 150° to 350° C. The accompanying curve (Fig. 3) shows the values which are customarily obtained, and in addition shows







- NOTCHED BAR VALUES — FOOT POUNDS -
50
45
40
35
30
25
20
15
10
5
100°
200°
300°
400°
500°
600°
— TEMPERING TEMPERATURES. °C —
EXPECTED RESULTS.
ACTUAL RESULTS.

FIG. 3.

the form of the curve which might reasonably be expected. Here again there is surely some constitutional alteration taking place, and it might reasonably be hoped that a sufficiently high powered Microscope would reveal it.

The theory which has probably had as much effect as any other upon recent scientific metallurgy is that known as the "amorphous cement" theory. This theory postulates the existence, between the crystals of a metal, of a thin layer of amorphous material which both separates and binds together the individual crystals. The properties of this amorphous metal are necessarily different from those of the crystals which it surrounds. The evidence for the existence of this layer is largely circumstantial, and though the evidence is powerful it would be decidedly stronger if the cement could actually be revealed. If a power of 10,000 failed to produce any further evidence of its existence it would seem difficult to imagine that it is really there

TABLE 2.

Tempering Temperature.	Notched bar value on tempered specimens	
	Cooled in air after tempering	Cooled in water after tempering
400°C.	8	8
500°C.	18	18
550°C.	7	30
600°C.	8	41
650°C.	8	53

Duralumin is a metal which has distinctly peculiar properties. If duralumin be quenched in water from a suitable temperature it is soft at first, but after standing for a time, e.g., 24 hours, the metal becomes quite hard. This change of properties is bound to be accompanied by some change of constitution, and a possible explanation of this change has recently been put forward by Dr. Jeffries. It seems certain, however, that the application of higher powers of microscopic examination would help materially in the investigation of this problem.

PHOTOMICROGRAPHS OF STEEL AND IRON SECTIONS AT HIGH MAGNIFICATION.

By Sir Robert Hadfield, Bart., D.Sc., D.Met., F.R.S., and Mr. T. G. Elliot, F.I.C.

Owing to the importance of the study of Microstructure much attention has been given to this subject since the days when the late Dr. H. C. Sorby, F.R.S., of Sheffield, originated, in 1857, this method of examining structures of various materials, including Iron and Steel. Indeed, one of the most striking features of the progress of Metallurgy in recent years is the great development of the use of microscopical methods of investigation. We submit some photomicros, Figs. 1 and 2, Plate A, representing some of the early work of Dr. Sorby at 9 magnifications. We also submit as a comparison, and in order to demonstrate the great advance in Metallography, Photomicrographs Figs. 3 to 25 showing later work of the writers of this Paper, in which magnifications are dealt with of 100 and up to no less than 8,000.

In carrying out this work, our best thanks are due to Mr. H. Wrighton, B.Met. for the assistance he has rendered and for the care and skill he has exercised in preparing the Photomicrographs accompanying our Paper.

One of us well remembers his conversations with Dr. Sorby regarding the micro study of his own early specimens of Manganese Steel, in 1883-1887. Dr. Sorby never turned away the youngest enquirer, and he little imagined when first describing his method in 1857 what an important aid this would eventually prove to Metallurgy. This is another instance of the great value to the Metallurgist of original work by the pure Scientist. Next to Sorby, this important branch of investigation owes more for its development to Arnold and Osmond than any others. It has been further advanced by Sauveur, Stead, Le Chatelier, Carpenter, Howe, Martens, Robin, Rosenhain, and many others.

Sorby bequeathed £15,000 to the Royal Society for the establishment of a Fellowship for the carrying on of original Scientific Research, the object specified being "to promote the discovery of new facts rather than the teaching of what is known," and stated that as far as possible the Researches should be carried out at the University of his own native City, Sheffield. To this Englishman, Sorby, the whole world has fully and freely given the credit of originating this important form of research which enables the structure of Iron and

its Alloys, including in that term the material generically known as "Steel," to be examined and understood in a manner which was before not possible. "Steel" is a wide term and to-day covers material which is practically pure Iron, for example, products containing 99.9 per cent. of Iron which offer high resistance to corrosion and oxidation and containing practically no Carbon, up to the material used for wortle or drawing plates which contain even more than 2 per cent. of Carbon.

Twenty-five years ago there were scarcely half-a-dozen Steel Works in the country which could lay claim to the possession of a Microscope suitable for metallographical examination. At the present time it may be safely said that no steel works of any size is without one. Nor is the use of the Microscope confined to the examination of Iron and Steel sections, for those engaged in the investigation of non-ferrous metals and alloys find its aid equally useful.

The history of Metallography, short as it is, is beyond the scope of the present paper. Naturally such history to be complete would record the improvements which have taken place in the construction of Lenses for metallographic work. One of the most important of these was the introduction of the Apochromatic Objective by means of which increased resolution was obtained, an absolute necessity for successful high power photomicrography. Unfortunately, as this Country had occasion to find out on the outbreak of War, the making of these objectives has in the past been largely in foreign hands. Steps are being taken to remedy this, and there is every reason to hope that here, as in other directions, in future, we shall be rendered entirely independent of the foreigner.

Great as have been the advances made in the microscopical examination of Iron and Steel, there still remains a wide field for exploration; for example, as regards methods which will enable increased magnifications to be obtained. It is wonderful what can be accomplished by the aid of the human eye alone, and even to-day the finest quality of crucible cast steel is, in its ingot form, first packed or sorted over in this manner. It is stated that an experienced workman can, by the eye, detect from the appearance of the fracture differences as small as .05 per cent. to .10 per cent. of Carbon. No doubt for many purposes an ordinary strong magnifying glass will tell much and more than the unaided eye can do, but when it is desired to reveal structures minutely, then the microscope is called in with great advantage. Magnifications of 10 or less, upwards to 1,000 or 1,500 are those most commonly used in metallography. Photomicrographs of larger magnifications than 1,500 have been rarely published. The Authors have, however, carried out experiments in order to obtain photographs of 5,000 and even 8,000 magnification, which may be of interest to this Society.

The very fine structures met with in alloy steels have made it desirable and induced the Authors to prepare in their research photomicrographs at higher magnifications than have hitherto been obtained. With great care and attention to necessary details, particulars of which are described in this Paper, we have been able to

obtain photographs of Iron and Steel sections at the high magnification of 8,000 diameters. To give an idea of what this means, it may be mentioned that the diameter of the actual field shown in a $3\frac{1}{4}''$ circle photograph at this magnification is only .00041″ or 1/2460″. The actual area of this field examined is .00000013 square inches. The polished section under micro-examination is usually about $\frac{1}{4}$ in. square. If the whole of this area were magnified 8,000 times it would yield a square about 55 yards by 55 yards, occupying an area of approximately 3,000 square yards, that is to say, not far away from three-quarters of an acre.

As is well known, the modern Microscope consists of two systems of lenses, the objective and the eye-piece. The objective gives an enlarged image of the object, and the eye-piece further magnifies this image. The high power photomicrographs given in this Paper are simply high magnifications by means of the eye-piece and extra camera extension of the image given by a 2 mm. objective, or in the case of the 8,000 magnifications by a 1.5 mm. objective. Whatever may be the quality of the image given by the objective—for example, as regards resolution—that quality is reproduced in the magnified image of the eye-piece. Thus, if the objective gives a blurred image, the blur is simply magnified. In other words, it is just as though a lantern slide were projected on the screen; if the slide is a good one we get a good picture, but if bad the picture will be no better because it is magnified. The essential aim, therefore, is to get a very clearly resolved image. This needs a special quality or virtue in the objective, and this virtue is called its resolving power.

For photomicrography at high magnifications, it is specially essential that an objective of high resolving power should be used. The effect of magnification without resolution is well illustrated by Figs. 3, 4 and 5 on Plate B. These photographs are all at 600 magnifications, but taken by objectives of low, medium, and high power respectively. In No. 3 the dark ground mass is left unresolved. No. 4 shows some resolution of this dark ground mass, but in No. 5 it is practically completely resolved into its two constituents, Ferrite and Cementite in lamellar form. In the course of a search for a really good 2 mm. oil immersion objective, for photomicrographic research, we found that results obtainable with a moderate Achromat, compared with those obtained with a good Apochromat, showed differences at least as great as is illustrated in Figs. 4 and 5.

An illustration of the microstructure of an Annealed Alloy steel, containing .84 per cent. Carbon and 1.12 per cent. Chromium, is shown at four different magnifications in Figs. 6, 7, 8, and 9 on Plate C. Although the resolution of the structure is the same in Figs. 7 and 8, because the same objective was used in each case, the effect of the increased magnification is to show in a striking manner the alternate white and dark constituents of the lamellar pearlite. This effect is further emphasised in a photograph of the same section at 8,000 magnifications, shown in Fig. 9. There is no doubt that this magnification taxed the lens somewhat beyond its capacity; however, the photograph is certainly a good one and worth including, if only to show the limit obtainable with the apparatus available at the present time.

Photomicrographs of Diatoms at 5,000 magnifications and over, taken by transmitted light, have been published; but so far as we are aware steel sections at such a high magnification have not been available. This may be easily accounted for by the difficulties in the way. Although, unfortunately, we are unable to indicate an easy path by which these difficulties may be avoided, we propose to show the means by which we endeavour to overcome them.

We have already laid stress on the need for an objective of high resolving power capable of giving good definition when combined with a properly compensated eyepiece of high magnifying power.

Probably the next most essential point is that the specimen to be photographed be properly etched. Deep etching is fatal; it causes pits and furrows in the surface of the piece which extend beyond the range of depth of focus, which with a high power objective, is naturally very limited. Therefore the most delicate etching is necessary, and this we find is usually best obtained with 5 per cent. Picric Acid in Alcohol.

The illumination of the specimen for photography is the next subject for attention. For high power photography the lighting should be as intense as possible. We use a 20 ampere arc lamp of the hand fed type, and this is found preferable to one mechanically fed. It is simple, has no mechanism to get out of order, and the carbons are not liable to re-adjustment at the critical moment, just when the plate is being exposed. Moreover, mechanically fed carbons are never so firm and free from vibration as those of the hand fed types. Alternating current at about 70 volts can be used with perfect success on a 20 ampere hand fed lamp, if cored carbons are used. This is a point on which emphasis should be laid, for the makers of our apparatus have always laid stress on the necessity for direct current for photomicrographic work. Tungsten Arc and Mercury Vapour Lamps have been more recently introduced for photomicrographic work, but we have had no opportunity of testing them.

The vertical illuminator attached to the Microscope should be a plain glass disc. We find a prism unsatisfactory for this work. The light should be focussed on the diaphragm of the vertical illuminator, and of course it must be perfectly central with the Microscope and the camera.

The iris diaphragm of the illuminator should only be closed as much as is necessary to get sufficient of the field sharp. Further closing of the diaphragm not only interferes with the resolution, but produces false images. An example of this effect is shown in Figs. 10 and 11, Plate D. Fig. 10 illustrates the result produced by closing the diaphragm too much, and Fig. 11 shows a correct image obtained by proper adjustment.

The diaphragm in the condenser system should be closed so that only the area to be photographed is illuminated.

For apochromatic objectives, a blue screen as a light filter should be used, and ordinary photographic plates. The specimen is focussed first of all on the ground glass screen of the camera, and finally adjusted

with the clear glass screen and the aid of the focussing magnifier. There is one point that has not been mentioned, which is quite obvious, and that is the necessity that the mounting of the whole photomicrographic apparatus should be perfectly rigid and free from vibration.

We have selected a few photomicrographs in order to show the effect of increasing magnifications on the same section, and also to illustrate well-known types of microstructure at high magnifications. The objectives used in obtaining photographs at 1,500 and over are stated on the plates.

The photographs on plates A, B, C and D have already been dealt with in the text.

PLATE E.—Figs. 12, 13, 14 and 15, show the microstructure of a Nickel Chromium Alloy Steel in two different conditions. Even at 1,500 magnifications the structure is seen to be very fine and close textured; it is rather more clearly defined at 5,000 magnifications, but a structure of this kind is very difficult to photograph owing to the want of contrast obtained even with the most careful etching.

PLATE F. Figs. 16, 17, 18 and 19 show the structure of Grey Cast Iron. The black constituent is Graphite, and the ground mass Pearlite. The four photographs on this plate illustrate very strikingly the advantage of higher magnifications in order to see clearly the details of a fine Pearlitic structure.

An additional photograph (Fig. 19a) is given on Plate F, which has been obtained by making an enlargement of the negative from which Fig. 18 was obtained. The enlargement has been so adjusted that its magnification is 5,000; a comparison is therefore obtainable with that of Fig. 19, which has been obtained by the direct method. There does not appear to be much to choose between the two Photographs in this instance, but in the case of more complicated subjects such as those illustrated in Figs. 20 to 22 on Plate G, the direct method of photomicrography, although very much more difficult than the indirect one of enlargement, is far preferable to the latter because the choice of field to be photographed is made at high magnification—an important advantage.

PLATE G.—Figs. 20, 21 and 22. Photographs 20 and 21 show the microstructure of a Carbon-Chromium steel in two different conditions, magnified 8,000 diameters. The former is a Sorbitic Pearlite structure, and the latter consists of Martensite and Troostite (black areas).—Fig. 22 shows the microstructure of a quenched Carbon steel at 8,000 magnifications, and is Troosto-Martensite.

PLATE H.—Figs. 23, 24 and 25. These photographs show the microstructure at 5,000 magnifications of a steel containing 1.41 per cent. Carbon in three different conditions. Fig. 23 is a typical Pearlite and Cementite structure; Fig. 24 a Martensitic structure, and Fig. 25 a structure of mixed Troostite and Cementite.

The value of higher magnification especially as illustrated in Figs. 8, 9 and 19 can be emphasised as a result of this research. These Photographs at higher magnifications show in a striking manner the details of a structure which at lower magnifications are only

very indistinctly seen; at the same time we are quite alive to the fact that they have not led us to any absolutely new discovery in the microstructure of Steel, and it is quite evident that there is an important field open for further investigations in this direction.

During the last few months we have been prosecuting enquiries in different directions with a view to obtaining apparatus which would enable us to attain much higher resolution than has been practicable with that at our disposal. While so far we have not been able to do this, several makers of apparatus and objectives in this Country are working at the problem, which we feel sure will soon be solved.

We have also been specially interested in the possibilities that might lie in the use of Ultra-violet Light for Photomicrography applied to Metal Sections. Who knows what new order of Phenomena may not be brought within our vision by the use of such apparatus. Researches are being made in this new field, and we all hope that such labours will be crowned with success.

In conclusion it is hoped that by presenting these Photomicrographs interest will be aroused in this special subject and that others will press forward investigations from which our general knowledge of the subject will benefit; also that the makers of the necessary Apparatus, whether Microscopes, Lenses or Lighting Appliances, will come forward with new developments which will enable still further fields to be explored in the now Unknown.

THE HIGH-POWER PHOTOMICROGRAPHY OF METALS.

By F. C. Thompson, D.Met., B.Sc. (Lecturer on Metallurgy in the University of Sheffield).

I.—General.

The high-power microscopical examination of metals is a matter of the greatest importance.

As Prof. Abbe has pointed out, however, and this forms practically the whole of the sermon which the author desires to preach, "empty magnification" unaccompanied by a corresponding resolving power is of no service whatever to the metallographer.

As is well known, it is impossible to produce a microscopical rendering of a point other than as a disc of definite dimensions the size of which depends on (1) the numerical aperture of the objective, (2) on the wave-length of the light employed, and (3) on the magnification. The diameter of this spurious disc $D = \frac{m \times \lambda}{2 \text{ N.A.}}$ where m is the magnification, λ the wave-length of the light used, and N.A. the numerical aperture of the objective. It will be at once seen that the image becomes less and less sharp as the wave-length of the light increases and as the ratio of the total magnification to that produced by the objective itself is raised.

As shown in Fig. 1, a succession of points may thus, if sufficiently near each other, merge into an apparently continuous line, the true structure of which would never be realised. Sorbite might in this way simulate pearlite. A very beautiful illustration of this effect in a diatom is given by Spitta, "Microscopy," Fig. 3A, Plate I. It will further be evident that a sorbite in which the diameter of the spurious disc exceeds the distance between the carbide globules will appear practically structureless, Fig. 2A, and that pearlite, the distance between the laminæ of which does not exceed this diameter, will lose its structure, Fig. 2B. The matter, therefore, is of very real practical import.

Abbe has shown that in the absence of certain diffraction spectra a line may be duplicated, or even rendered as three. Although in metallurgical work such results are unlikely—they would, for instance, double or treble the fineness of a laminated eutectic—the possibility of such spurious effects at very high magnifications should always be borne in mind.

According to Spitta the limit of magnification to which it is permissible to go with light of wave-length 540 $\mu\mu$ must never exceed 1,000 times the numerical aperture of the objective.

It would thus appear that the best method of approach to the very high magnifications suggested lies at the present time in the use of ultra-violet "light" of very short wave-length. Since glass is opaque to such vibrations, quartz or fused silica must be used as the optical material of all lenses, vertical illuminators, etc. In connection with metallographic work, since the objective acts as its own condenser, and since no slips or cover glasses are required, such a system is much cheaper than it can be when using transmitted

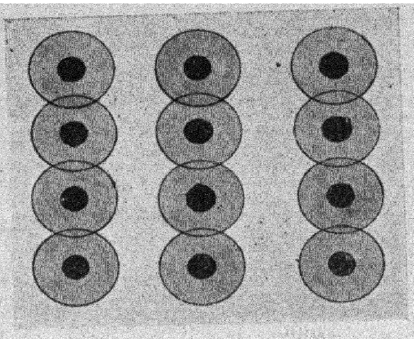
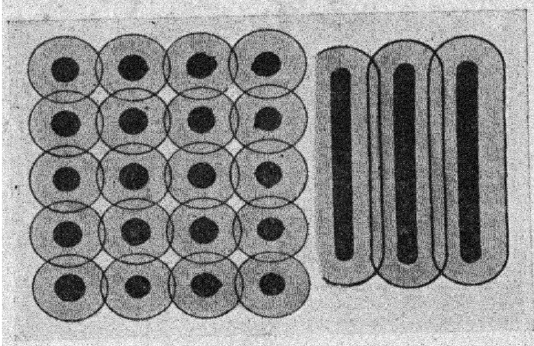
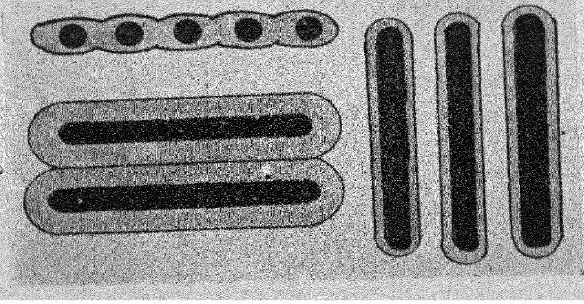


FIG. 1.
Effect of Halo in Producing a Spurious Lamination.



A B

FIG. 2.
Structureless Rendering of Sorbite or Pearlite.



C A B

"light." The lenses in the objective are constructed of fused silica, those of the eye-piece of quartz. A mixture of glycerine and water of the required refractive index is used as an immersion liquid, and focussing is carried out by the use of a fluorescent screen. So far as the author is aware the highest power silica objective so far made is the 1.7 mm. with 1.25 N.A. In virtue, however, of the shortness of the wave-length used, 275 $\mu\mu$, this is equivalent to about 2.5 N.A., using white light, and according to the rule given above could be used for critical work up to 2,500 diams., which would be obtained with, say, a × 15 eye-piece and a camera length of 31 c.m.s. There appears to be a very big field of usefulness for this system in metallographic research work.

II.—The Davidson "Super-Microscope."

The claims made for this instrument in connection with very high magnifications—up to 15,000 diams.—render a consideration of its capabilities germane to this paper. In essence, an image is formed in the usual manner by a microscope objective, which image is then magnified by a second microscope, with or without an eye-piece. Such a procedure demands for the highest magnifications an amplification of the primary image so high that no objective at present made will stand it In theory the instrument is unsound, and in practice, so far as the author's observations go, the results at high magnifications are very poor. Through the kindness of Sir Robert Hadfield the apparatus was sent to the author some two or three years ago for investigation. Since then the mechanical side has been considerably improved, the optical arrangement remaining, however, unchanged. Quite recently another opportunity has arisen for his observation of the instrument, but his view is unchanged In the trial two test objects were chosen, one a very fine sorbitic structure in a quenched and tempered tool steel, the other a normalised Bessemer steel with 0.4 per cent. carbon, and 1 per cent. manganese, the pearlite in which was finely laminated. With a magnification of 1,000 diams., using Zeiss lenses and the ordinary apparatus, both objects were easily resolved. At the same magnification, however, the "Super-microscope" failed entirely. The sorbitic material appeared structureless, while in the case of the pearlite only the faintest suggestion of lamination could be detected. At higher magnifications the apparatus is utterly valueless.

The very claim put forward for the instrument that it possesses great depth of focus is in itself an admission that the resolving power is poor, since these two factors vary inversely as each other. Since for the purpose at present under consideration, viz., high magnification of metallic structure, depth of focus is of no importance, while resolution is a matter of prime weight, the remarks previously made are still further substantiated.

For other purposes, as a telescope, or for low power examination of a metallic fracture where great depth of focus is quite necessary, the apparatus probably offers very real advantages. In particular, perhaps, may be mentioned direct measurements from some distance of changes in length, such as are needed in a determination of co-efficient of thermal expansion.

III.—The Reichert Microscope.

This instrument, which is too well known to need description here, has often been regarded as a convenient apparatus for use in those industrial establishments where convenience and rapidity of working are, perhaps, of somewhat greater importance than the very finest definition and resolving power. An investigation recently made by Professor Carl Benedicks and E. Waldow (Jern-Kontorets Annaler, 1918, 537) has shown, however, that far from such being the case, photographs of the very highest quality can be obtained. Several micrographs published by these workers at 1,200 diams. leave little or nothing to be desired. The perfection is further illustrated by an enlargement at 3,500 diams. which constitutes one of the most excellent photomicrographs of steel at such a magnification ever obtained. This magnification, however, has only been used to show what sort of effect is the best at present obtainable, and does not represent one which will yield critical results. Around the globules and laminae of Fe_3C are thick black halos up to and exceeding 0.5 mm. thick.

The authors point out the much lower quality of picture obtained when the prism vertical illuminator is used as compared with that when the plain disc is chosen. This fact, first pointed out by Professor Benedicks himself, is one of prime importance in connection with high power microscopy. Since in one direction the prism cuts off half of the back lens of the objective, the resolving power is curtailed accordingly. To pay big prices for Zeiss lenses of high N.A. and then deliberately to cut down by the prism illuminator the resolving power to much less than that obtainable with a lens of similar focal length at a fraction of the cost, argues a very poor acquaintance with the theory of the instrument. Since this loss of resolution operates chiefly in one direction, there is a tendency for a circular object to be drawn out into an ellipse. Further, rows of globules oriented in the direction of the longer axis of the ellipse are much more likely than ever to be rendered as a continuous band, while laminated structures may appear structureless or be correctly resolved, according to the direction, Fig. 3. The marked superiority of the disc should need no further emphasis.

As one would expect, the strength of the source of light is shown to be without effect on the quality of the photograph produced. When vibration is considered, however, and this is rarely absent from steel works laboratories, the much shorter exposure required with powerful arc illumination, renders it then possible to obtain sharper negatives than with weaker lighting. In connection with vibration it is suggested that the objective should be separated from the body tube, which will result in a considerable decrease of mass in those parts specially sensitive to vibration, whereby the amplitude of the latter will be reduced and non-recurring.

While considering this point, the following is of importance. Given a certain primary image, this can be magnified in two ways. In the first place, it may be eye-pieced strongly, or alternatively, an eye-piece of lower magnification can be used with a long camera extension. Given absolutely rigid conditions there does not appear to be very much to choose between the two methods, although perhaps the long camera

is better since, in general, a larger field would be obtained. In cases where vibration may make its influence felt, long camera lengths rarely yield satisfactory results, since the extent of the oscillations increases with the length. It would appear, therefore, that in this case on the few occasions when it is necessary to push the magnification of a given image as far as possible, it is advisable to use a high eye-piece and short camera extension rather than the reverse.

In connection with the use of the projection eye-pieces it was discovered that the setting, *i.e.*, the relative positions of eye and field lens, which requires adjustment for different lengths of camera, is dependent not only on this and on the ocular used, but also upon the objective. The effect of the latter is shown to be considerable, and the statement made that "the possibility of movement of a projection eye-piece is practically superfluous," must be admitted to carry weight, although it is at variance with present notions. Four diagrams are given in which the camera length is related to the best setting of the eye-piece for objectives of different focal lengths.

In conclusion, another direction in which modifications of existing methods might be of value may be pointed out. Cases may well arise in which extremely oblique rays would reveal a structure in what, when viewed directly, appears to be a structureless constituent The insertion of suitable diaphragms behind the back lens to effect this would facilitate at times the resolution of a "line" into its component dots. The general rendering of an object would be deleteriously effected by such a procedure, but in certain cases distinct advantages might be gained.

ILLUMINATION IN MICRO-METALLOGRAPHY.

By Henry M. Sayers.

In discussing this subject before this audience it is only necessary to set out certain propositions as assumed and accepted to give form and cohesion to the whole treatment. These assumed propositions are as follows:—

1. Correct illumination is essential to obtain the best results of which the objectives and oculars used are capable.

2. The principles of correct illumination are the same for the examination of opaque objects such as those studied in metallography and that of the (partially) transparent objects examined by transmitted light.

3. The illumination which permits of the utilisation of the maximum potential resolving and defining power of any objective is given by an image of the source of light projected on to the object, formed by cones of light with apex angles approximating to the angular aperture of the objective in the medium used.

4. Micro-metallography implies the use of the highest optical power available—though not necessarily in every case—and the use of photographic records.

5. Micro-metallography implies the use of some form of "vertical illuminator," and of the objective as a condenser, in all but quite low-power work.

6. It is desirable to shorten photographic exposures as much as possible, especially at high magnifications, and to avoid "glare" which reduces contrast and obscures fine detail.

7. The present effective magnification has an upper limit of about 1,000 diams., due to the limitation of the N.A. of objectives to a maximum of about 1.4 by the optical constants of the glasses and immersion media available. Any increase in N.A. and effective magnification will require a corresponding increase in illumination efficiency.

Proposition 5 sets out two conditions which constitute important differences in the application of correct illumination to opaque and to transparent objects, and give rise to the principal difficulties in attaining good illumination in metallography. The vertical illuminator entails a great loss of light. The use of the objective as the condenser also entails limitations which do not arise in the same degree when these two components of the optical system are independent.

If a total reflection prism is used as the vertical illuminator it may reflect nearly 100 per cent. of the light falling on it into the objective, but it intercepts all the light from the objective passing towards the image plane which falls on it. In the best case the prism occupies half the objective aperture, only half the objective receives light from it, and half the light going to the image is intercepted. Hence only 25 per cent. of the illuminating beam can be utilised in the image. If the prism is either larger or smaller the percentage of light getting through to the image is less than 25 per cent.

Similarly, if a cover-glass type of reflector is used the maximum illumination possible theoretically would be given if the reflector reflected 50 per cent. of the light and transmitted 50 per cent. The result would be 25 per cent. of the light utilised. No cover-glass type reflector does nearly so well as this. Measurements of a clear cover-glass have given me a reflective power of 13.8 per cent. compared with a silvered total reflection prism, and a transmission of 66 per cent., with the glass inclined at 45° to the beam. The resultant for the image illumination is therefore 13.8 × 66 per cent. or 9.2 per cent. for the image. A semi-platinised cover-glass (not made for the purpose) gave 38 per cent. reflection, but only 21.5 per cent. transmission or 8 17 per cent. for the image The light, too, was brownish yellow.

The prism reflector, while much superior to the cover-glass in respect to illumination, cuts down the effective aperture of the objective, both as a condenser and as an objective, and does this unsymmetrically to the detriment of its resolving power. This is probably the reason why prism reflectors are never made to cover nearly so much as half the objective aperture, and they are consequently not in practice much better than cover-glasses in respect to brightness of image.

The diminution of light intensity in the image compared with that reflected by the object is proportional to the square of the lineal magnification, increased by absorption and reflection in the optical system. With 100 diameters the light intensity at the image is under one ten-thousandth, and with 1,000 diameters under one-millionth part of the light reflected by the object. Allowing for the loss due to the vertical reflector it is for the two magnifications mentioned less than one forty-thousandth and one four-millionth part respectively of the light intensity of the source for any part of the object which has perfect reflecting power, assuming that the image of the source is as bright as the source itself. As these small fractions are on assumptions of 100 per cent. efficiency for every stage of reflection and refraction between the source and the image, which is unattainable everywhere, it may be roughly estimated that the actual fractions of the source brightness in the brightest points of the image will be more nearly one ten-thousandth and one ten-millionth respectively. The most obvious improvement would be the devising of a vertical reflector giving an efficiency of combined reflection and transmission approximating to 25 per cent. without cutting down the objective aperture.

The exposure required is that for the "shadows" of the object, *i.e.*, for the darkest parts which show perceptible detail. It follows that to get reasonable exposure times only light sources of great intrinsic brilliancy are of practical use for photographic work. The total candle-power of the radiant is no criterion by itself, it is candle-power per unit area of radiating surface which counts.

Of the available sources the positive crater of the carbon arc is the most brilliant. After that come in descending order the Nernst lamp, the tungsten arc (or Pointolite), the half-watt metal filament lamp, and the oxy-hydrogen lime-light. The last named is the only light source depending on combustion at all suitable for the purpose,

but it requires cumbersome accessories and so much attention that it need hardly be considered unless an electric supply is quite out of reach.

The mercury vapour lamp ought to be mentioned, but the writer has no experience of it, can find no information as to its intrinsic brilliancy, and has seen no form of the lamp which is convenient for metallography. The nearly monochromatic quality of the light is in its favour, and it is probably capable of being put into a very useful and efficient shape for the purpose.

The arc crater gives the highest light intensity. With the requisite attention it is unsurpassable in rapidity and quality of negatives. But it has some disadvantages. The positive crater is somewhat obscured by the tip of the negative carbon, the crater surface is not always of uniform brilliancy all over, and the crater may shift during an exposure from one part of the carbon to another. Such unsteadiness may arise from the arc length being too great from an endeavour to get the negative tip out of the field of view; from impurities in the carbons, or from draughts The arc length has to be adjusted at intervals of a few minutes. The arc does not steady down until it has been burning for several minutes. It is therefore an item of the equipment to be attended to and waited on. The arc gives off a large amount of radiant heat which has to be considered in relation to any auxiliary lens system required. It therefore leaves something to be desired in point of convenience and its rapidity in photographing is subject to some discount for the time taken in attending to it.

The Nernst lamp is excellent in many ways. It requires no globe, no attention, and is quite steady. It gives off relatively little radiant heat. It can be used on either continuous or alternating current. The shape of the radiant surface, a rod of quite small diameter is somewhat inconvenient, as it calls for very accurate centering of any auxiliary lens system It has been unobtainable in this country for some years, as it is made only in Germany. The small diameter of the rod obliges one to magnify it considerably by the auxiliary lens system used, so that the effective brilliancy is not so great as might appear. With a one-ampere Nernst lamp I have done a good deal of work on steel at 700 to 1,000 diameters, and find the exposure required to be from five to ten minutes at such powers, using fast plates and a light filter.

The Pointolite or tungsten arc is free from the inconveniences of the carbon arc. The source of the light is a small ball of tungsten which appears in the field of view as a disc of uniform brilliancy fixed in position. Its intrinsic brilliancy from some rough tests of my own seems to be about one-third that of the carbon arc crater. It lights up at once, is normal in a few seconds, requires no adjustment or attention, and gives off a relatively small amount of radiant heat. It is very promising and the larger sizes which are being developed may prove to be as quick in work as the carbon arc, when the absence of attention and unsteadiness are taken into account. Like the carbon arc, it requires continuous current for its operation.

Half-watt lamps with straight filaments as made for motor-car head lights are quite useful. Their intrinsic brilliancy is little inferior to that of the tungsten arc. The small diameter of the coiled filament is open to the same objection as the Nernst filament, *i.e.*, it has to be

much magnified to fill the field of view, so that the effective brilliancy is reduced. Moreover the separate turns of the spiral become visible in a critical image. These small lamps can be run from a few ignition cells, so that they are convenient for portable use. Run from an ordinary supply circuit they require either a resistance or a transformer to reduce the pressure to 6 or 8 volts. Good work has been done at high powers on steel with a 6-volt 4-ampere half-watt lamp, but the exposure is two to three times as great as with a Nernst lamp. Up to 150 diameters this exposure is reckoned in seconds, so the difference is not important, but for high powers the exposure goes up to several minutes (15 to 20), it counts where much work has to be done. Long exposures are objectionable not only because they limit the speed of work, but also because they increase the risk of disturbance of the image by vibration.

The illuminations needed to give short exposures are far too bright for comfort in visual examination. The interposition of a piece of fine-grained ground glass is a simple remedy. It can be put anywhere between the light source and the vertical reflector and no adjustment is disturbed. The final focussing must be done on the ground glass of the camera, where the full illumination will not be found excessive for the purpose.

Anyone starting on micro-metallography will find his initiation much easier if he tries first visual and photographic work by transmitted light on transparent objects. As the sub-stage condenser is independent of the objective it is much easier to try variations of focus and illumination, and the knowledge so gained helps very much to recognise proper and improper condition in opaque work. Good objects for such training are section of Echinus spine for low powers, and diatoms of various fineness of structure for the higher ones. A student who can get a good dark round negative of Echinus spine at 100 diameters, and good " black-dot " negatives of Pleurosigma Angulatum or Surirella Gemma at 1,000 diameters with an oil immersion objective will find work on metals much simpler than if he came to it without such practice. The superior resolving power and definition of a given objective with the sharp image of the illuminant focussed on the object from a sub-stage condenser of aperture comparable to that of the objective will be appreciated.

In metallography (excepting with the very low powers) the objective plays the part of the sub-stage condenser as well as its own. To obtain a sharp image of the source of light upon the object when the object is focussed to the eye-piece, certain distance relations between the illuminant, the objective, the object, and the image plane must be observed. They are simple. The light source must be at the same distance from the back lens of the objective as the image plane, the distances being measured along the path of the light in each case Obviously the source and its image on the object are at the conjugate focii of the objective; and the object and its image are at equal conjugate focii. An immediate consequence of this relation is that the illuminated field or useful part of the image formed by the objective is of the same dimensions as the source (real or virtual) of light itself. If, for example, the source of light is the crater of an arc, one-tenth of an inch in diameter, the usefully illuminated part of the real image

formed by the objective will also be one-tenth of an inch in diameter. This identity of dimensions is independent of the power of the objective. A two-third inch with a power of 8 and a one-twelfth inch with a power of 100 with both give an illuminated circle of one-tenth inch diameter in the image plane, provided that the conditions of critical illumination are observed. If the total magnification on the camera screen is ten times the objective image magnification, the effective field will be one inch in diameter. This is generally too small for practical use, and is much smaller than the field which the objective can cover. One wants a field at least three inches in diameter to cover a quarter plate. The assumed magnification of ten due to the ocular and camera length combined is about as much as the best objectives will usefully stand. So that to cover a quarter plate the radiant should be from a third to a half inch in diameter.

Unfortunately the avallable sources of light are of small area. An arc crater of a quarter-of-an-inch diameter corresponds to an arc current of 30 to 40 amperes, and is not really large enough. As the crater diameter increases only as the square root of the current, one would require a searchlight arc, with many tens of amperes to give a crater three-quarters of an inch in diameter, which is about the ideal size to fill an eye-piece. Such an arc is not practicable. Even a 40 ampere arc gives out too much radiant heat to be brought within the few inches of the microscope corresponding to the posterior focus of the objective. The same difficulty of small area is true of the other available sources. The 100 candle-power Pointolite has a radiant surface about one-tenth of an inch diameter. The Nernst and half-watt lamps have filaments of much smaller diameter. There seems no good reason why a half-watt spiral lamp filament should not be made one-third or one half-inch diameter. There may be manufacturing difficulties, or it may be that the makers have not seen that there is any use for such lamps. If made the spiral, or rather helix should be flattened to bring the radiant surface as nearly as possible into a plane.

The actual radiant surface therefore has to be magnified in some way to give a field of sufficient area. The simplest way is to use a short focus condenser to project near the upper lens of the objective an image of the radiant. This can be focussed on to the stop of the vertical illuminator, and the fine focussing done by eye. The image thrown on the object is that of the aperture of the condensing lens which is then at the posterior focus of the objective. A condenser of the Nelson type of two inches full diameter, stopped down to one inch aperture works well. It must be carefully centered to the radiant, and both must lie on a line at right angles to the optical axis of the microscope. To make these adjustments readily, some form of mounting equivalent to an optical bench, with vertical and horizontal movements to either the lamp or the lens is necessary. If the lens is always used for the same stand, it can be fixed at the height of the optical axis, and the adjustments for centering made on the lamp carrier. Movement to and from the microscope to adjust the lens distance to the optical tube length in use—which may be different with different combinations of objectives and oculars—and some movement parallel to the body to allow for the range of movement of the illuminator aperture, are necessary. These statements hold true for any of the auxiliary arrangements described.

The condenser must be of short focus in order to take in a large cone of light from the radiant. The Nelson condenser mentioned has a working distance of about one-and-a-half inches. This is too short for an arc of even ten amperes, but with a Nernst or half-watt lamp up to 100 candle power the heat will not injure it. The Pointolite lamp of 100 candle power has a bulb which is just too large for such a condenser to focus at the required distance.

Another arrangement is to set up a screen with an aperture of the required size, say seven-eighths inch to one inch, which may conveniently be an iris, at the required distance and to throw on that aperture a magnified image of the radiant. The image formed by the objective on the object will then be a reduced one of the radiant. This arrangement takes up a good deal of room. Thus if the aperture is one inch in diameter and the radiant quarter-inch diameter, and a lens of four inches focal length is used, the total distance from the microscope body will be from 32 to 36 inches, which is awkward for making the adjustments, attention to the arc, etc. It is doubtful whether a lens of four inches focal length could be safely used with an arc giving a quarter-inch diameter crater. A six-inch or eight-inch focus would probably be required and proportionately more distance occupied. It follows that there is not really much advantage in using radiants larger than those which permit of the use of lenses of about two inches focus. More light is produced, but no more is utilised.

A third method is to present to the objective a virtual image of the radiant, *i.e.*, to use an auxiliary lens as a simple magnifier, the objective taking the place of the eye. The focal length difficulty comes in again, as the lens must be closer to the radiant than its focal length. A lens combination with its equivalent plane well in front of it, so that the working distance from the radiant is greater than the focal length, gets over this. Such a combination which I have used with success is a Nelson condenser with a flint concave between it and the microscope. The combination is really a microscope of the Brucke type. The concave is placed close up to the aperture of the vertical illuminator, and focussed by moving the radiant to or from it. As the radiant and condensing combination are both within a few inches of the microscope body, adjustments are easily made while observing the object. The image given by the objective is a real image of the radiant. The magnification may easily be ten times.

Whatever arrangement is used there should be provision for interposing a ground glass or light filter in the path of the beam. For metallography a light filter is not needed for securing contrast as in stained specimens photographed by transmitted light, but for cutting out the chromatic residuals given by even the best objectives. The sharpest visual focussing on the camera screen without a filter fails to give an equally sharp negative. A green filter, such as the F line filter, or a malachite green gives sharper results without a great increase in exposure.

With either of the two first named auxiliary arrangements a glass micrometer can be placed in the focal plane which is the virtual radiant and the scale image focussed on the specimen can be photographed at the same time. This is equivalent to an eye-piece micrometer. Its size on the camera screen is a measure of the magnification

due to the ocular and camera length. Like any eye-piece micrometer, its actual value needs to be calibrated against a stage micrometer, but it is available with any eye-piece.

There remains the difficulty of "glare." The worst source of this trouble is reflection from the surfaces of the objective lenses. The upper convex surfaces are the strongest reflectors. Fortunately the condition that the illuminating beam should fall as if it proceeded from the image plane, means that it is made up of divergent rays which a convex reflector cannot bring to a focus, but reflects with an increased divergence. Consequently with the light focussed correctly only a small spot of glare light appears at the apex of the upper objective lens. The bulk of the reflected light is scattered to the tube sides Obviously the objective mount and body tube should be well blacked inside. Reflections from the inside of lamp bulbs and other stray light may give trouble. It is best to keep all these away by a screen, which may be the mount of the auxiliary lens or aperture. Another source of glare is reflection from the front lens of the objective. It is only troublesome with dry objectives of short working distance. With those of 2/3 inch and over it is not serious, but it is hardly possible to get negatives with good contrast with dry objectives of 1/4 or 1/6 inch. Perhaps this is one reason for the fact that very little metal work is done at magnifications between 150 diameters, the upper limit of a 2/3 inch or 16 mm. objective, and 700 diameters corresponding to a 1/12 inch or 2 mm. oil immersion. One can, of course, get intermediate magnifications by using low ocular and camera length with an oil immersion, but the field covered is too small for the general view required. The Zeiss 3½ mm. or 1/7 inch oil immersion fills the gap very well. I have tried to get English firms to make a similar lens, and one maker listed a 1/6 inch oil immersion for metallurgical purposes before the war, but has ceased to make it. I would suggest that a 6 mm. or 8 mm. oil immersion should be made for the work. The working distance need not be too great for the oil contact, no cover glass has to be allowed for, conditions favourable to giving the objective a relatively large N.A. without introducing specially great manufacturing difficulties. The Zeiss lens mentioned was quite cheap, and of excellent performance. A one inch or 2/3 inch of about .30 N.A., a 1/3 or 1/4 inch oil immersion of about .70 N.A., and a 1/12 inch of 1.3 to 1.4 N.A. would furnish a metallographer with a battery serving all the purposes.

For low power work there is room to put the vertical illuminator below the objective, and it can be arranged to give either vertical or oblique light. Even here it will be found advantageous to use an image of the radiant formed by an auxiliary lens.

To sum up the above, it may be said that the items in which improvement is desirable are the following:—

1. A transparent vertical illuminator which shall get nearer the theoretical perfection of reflecting 50 per cent. and transmitting 50 per cent. of the light incident on it at 45°, without colouring the transmitted light. Optically worked glass lightly platinised seems the most promising.

2. A light source of uniform and steady high brilliancy presenting an area of half-an-inch square or a little more, to which a condenser of 2 inch working distance can be focussed without damage from

radiant heat. Either the half-watt or the Pointolite lamp may be able to meet this. The limitation of bulb size is important.

3. Oil immersion objectives intermediate in focal length and aperture between the 2/3 inch and the 1/12 inch, well corrected for colour. If anything can be done to reduce glare from internal reflection in the objectives designed for metallography it will be an advantage.

4. An auxiliary condenser combination with a long working distance compared with its focal length to be used to present a magnified virtual image of the radiant to the objective. Suitable specification would be:—

Focal length, 1½ inches to 2 inches.
Working distance—anterior—3 inches to 4 inches.
Clear aperture, ¾ inch to 1 inch.
Well corrected spherically and chromatically.
Mounted with a flange or a flanged collar.
Cost reasonable.

5. A simple firm optical bench or geometric slide arrangement with carriers for lamp and condenser at heights corresponding to those of usual microscopic axes when in the horizontal and vertical positions. The whole bench or slide to be capable of movement parallel to the microscope axis for 2 or 3 inches.

THE USE AND NEED OF THE MICROSCOPE IN ENGINEERING WORKS.

By S. Whyte, B.Sc.

It is not necessary in these days to set out in detail the practical help which is derived from the use of the microscope in engineering. Everyone knows the great benefit it has been in controlling the question of steel supplies and their heat treatment. By its means inherent defects in the steel are discovered. Troubles may arise at the steel works through bad ingot pouring, and any pipes or seams which occur in the portion of the ingot which is used finds its way into the billets and bars. Also, faults may arise in the forging or stamping of the steel which are difficult to detect without a microscope. For finished parts the microscope is almost essential in working out and standardising the best methods of heat-treatment, and in the event of failures of these parts in service, in helping to discover the processes by which these failures originate and develop. This by no means exhausts the list of uses to which the microscope can be applied in examination of metals for engineering works, as the properties of castings—both ferrous and non-ferrous—can be co-related with their various micro-constituents and their distribution or crystalline arrangement.

The writer does not propose dealing in detail with the various branches in which, from his own experience, he has found the microscope to be of great value. It is sufficient to say in passing that the microscope ought to be, and will be in the near future, an essential part of the average engineering works equipment, especially where the products being manufactured are subjected to live loads, and on which the safety of life depends.

The purposes for which the microscope is used, as outlined above, are three-fold, and endless examples could be given.

First, in the examination of raw material, as supplied by the steel makers and stampers. It is not enough in all cases to buy merely to chemical specifications, as two pieces giving the same analysis may differ in their usefulness. One may be sound, while the other shows segregations and results of ingot piping. Faults such as these, however, are becoming rare, as the improvements in recent years, specially in regard to ingot casting, have done much to eliminate them. It is, however, still important that samples of new types of stampings, as they come from the makers, should be examined for incipient cracks or "laps" of oxide driven into the material, specially when the stampings are intricate, and the steels used are alloy steels. It is impossible to tell, other than by the microscope, that some of these flaws exist, and it will help the stamper to correct his dies, and will save time and expense and the possibility of subsequent failures from this cause, if defects can be detected from the beginning. Micro. No. I. is an example of this type of defect.

Secondly, and what is more important from the engineer's point of view, the microscope is a great help in arriving at the best heat-treatment temperatures for his steel. It is absurd to buy expensive high-grade alloy steels, and not use every means of obtaining the best results from them. It is equally extravagant to buy high-speed steel for tools

and waste it, and much time in the machine shop, through bad hardening. For machine parts, pyrometers and testing machines are necessary in standardising methods after the temperatures have been established, but with high-speed steel, where the hardening temperatures are usually high, the recording of these temperatures is not so reliable and calls for all the more precaution in testing the conditions by micro-examination of the steel after hardening. Micros. Nos. II. and III. show the structure of an 18 per cent. tungsten steel heated to a satisfactory temperature, and overheated, respectively. The overheated, or burnt structure of No. III., shows the large crystals of austenite with oxide beginning to form round their boundaries. On the other hand, the best cutting properties of the steel are not brought out unless the steel is heated to a temperature high enough to diffuse all the free iron tungstide, which is present in the annealed condition. Micro. No. IV. shows the same high speed steel where the hardening temperature has not been high enough or the time of soaking not long enough, and too much free tungstide is still present.

Thirdly, and most important for the engineer, is the use of the microscope in helping to locate the causes of failures, and in working out the processes by which these fractures develop. The causes of failure are numerous, and apart from those due to inherent defects in the steel as mentioned above, the principal one is that of " fatigue." In " fatigue " fractures, the origin is usually found in a weakness of design or in using steel of too low an elastic limit. Sometimes a piece of non-elastic slag, occuring at a point of maximum stress, sets up local stresses high enough to start a fracture. In designing machines, a radius replaces a sharp corner whenever possible, when working stresses are set up at these points, so that the stresses shall be distributed as evenly as possible. Sometimes one finds an accidental notch, such as a file mark. in a radius, which sets up a " fatigue " fracture. An example of this may be given, as it brings out points in connection with the microscope objectives, which appear to be worthy of consideration. Micro. No. V. shows such a V-notch, accidentally made by a file in the radius at the foot of a stop in a machine gun lock mechanism, which received rapidly repeated blows. The notch has concentrated the stresses to such an extent that overstraining of the material has taken place, and a crack is seen originating at the apex of the notch. The crack, as it develops, is seen to be deflected through a slag inclusion, Micro. No. VI., and in other places in the same specimen it was noticed that " strain picture " was highly developed round these slag inclusions, although fracture had not commenced.

In microphotograph No. VII. this strain structure is also seen around the end of the crack which had penetrated about 1-16 in.

It is in cases such as the above that good objectives are necessary, and more so when alloy steels are being examined. In non-ferrous metals the crystal grains are usually much larger, and strain structure is easily resolved with comparatively low magnifications. Microphotograph No. VIII. shows a brass which had been strained during machining.

It is in photographing the fine-grained steels that the differences in the microscope objectives show up. In photographing Micro. No. VII. the secondary spectrum of the achromats would give bad definition but, with the elimination of this in the apochromats, by the union

of three colours of the spectrum at one point instead of two in the achromats, a great improvement is effected. This, with the correction for spherical aberration in two colours, gives an image of greater sharpness for either white or monochromatic light.

For low power work, however, and for certain subjects on higher power work, a flatter field and better results can often be obtained by achromatic objectives, as the larger aperture of the apochromats tends to give a slight curvature of the image, which even the compensating or projection ocular cannot entirely correct.

At the same time it is felt that even the best made German objectives do not give enough magnification for micro-photography, as the very fine structure of some alloy steels are at present most difficult to resolve, and much that is now impossible to see might be brought out under higher magnifications. Microphotographs Nos. IX. and X. show " etch figures " in crystals of pure nickel. These serve to determine the crystalline system to which nickel belongs. The crystal in Photograph No. IX. shows a twinning plane, and the consequent difference of orientation as shown by the " etching pits." It is impossible to say what internal structures might be brought out in heat-treated alloy steels by higher magnifications, as the crystal grains are so much smaller than those of the nickel shown in Photographs IX. and X.

For metallographic work the following provisions on the microscope seem, to the writer, to be advisable for good work. The microscope should be usable in the horizontal position.

The stage should have a mechanical movement in two directions, at right angles to each other. The stage should also have a racking motion for focussing, as it is usually more suitable to rough focus by this means in preference to that on the tube, as it does away with the necessity of altering the position of the optical bench. The fine adjustment is usually on the tube of the microscope, and this is the most convenient place.

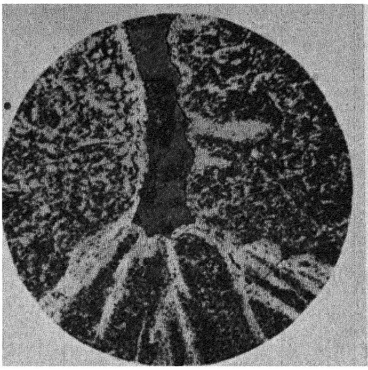
Ordinary Huygenian eye-pieces are most suitable for achromatic objectives, while for the apochromatic objectives special compensating eye-pieces are necessary. For photography a projection eye-piece gives the best results.

The disc illuminator gives most satisfactory results and, with a diaphragm between it and the source of light, good definition can be obtained.

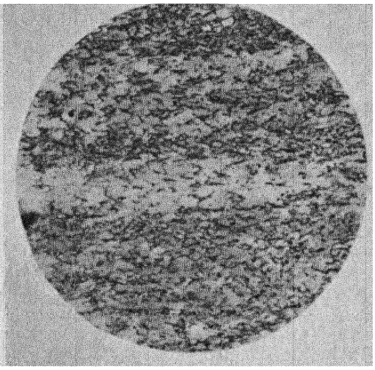
The objectives as mentioned previously should be used according to the subject—the achromats give every satisfaction for the general run of metallurgical work and, even in photography, are often preferable to the apochromats, by giving a flatter field. However, when photographic records of very fine detail are desired there is no doubt of the superiority of the apochromats for the purpose.

It seems to be desirable to be able to obtain much higher magnifications than are at present obtainable by the present objectives, but, in all probability, improvements in the methods of polishing the specimens will also have to be developed to secure a surface good enough to bear the higher magnification.

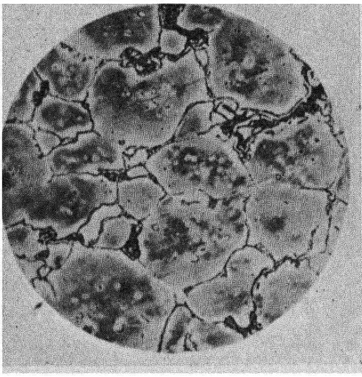
There is undoubtedly a great future before the microscope in its application to engineering work, in relation to designs, steel and its heat-treatment.



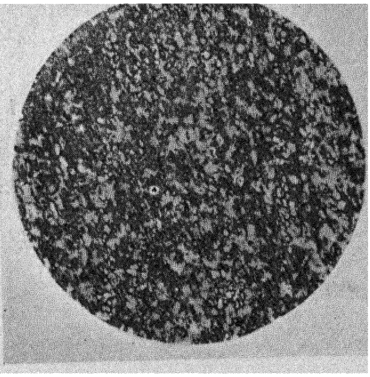
Spec.: Small Forging.
Illum.: Vertical.
Camera: 66 cms. Obj.: 20 mm.
Ocu.: Projn. Mag.: 90 diams.
Etched: Picric Acid.
Remarks: Slag driven into steel along with some decarbonised layers from the surface. .42% C. steel.



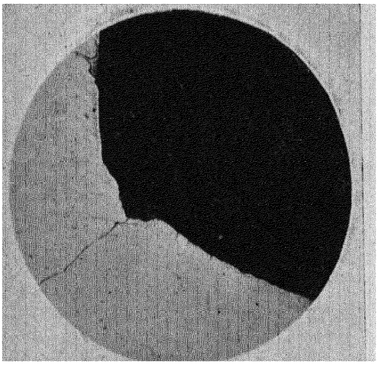
Spec.: High-speed Steel.
Illum.: Vertical.
Camera: 78 cms. Obj.: 4 mm.
Ocu.: Projn. Mag.: 500 diams.
Etched: Picric Acid.
Remarks: Fine Grains of Austenite with traces of free tungstede steel unabsorbed. (White globules.)



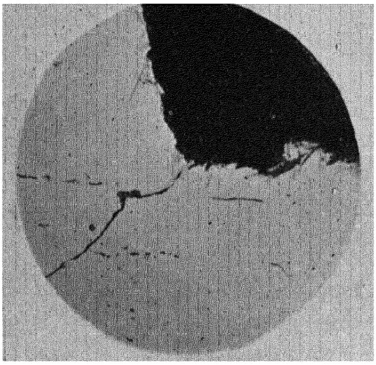
Spec.: High-speed Steel.
Illum.: Vertical.
Camera: 66 cms. Obj.: 2 mm.
Ocu.: Projn. Mag.: 1,000 diams.
Etched: Picric Acid.
Remarks: Large grains of Austenite surrounded by oxide.



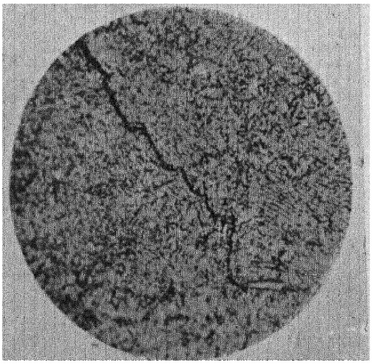
Spec.: High-speed Steel.
Illum.: Vertical.
Camera: 78 cms. Obj.: 4 mm.
Ocu.: Projn. Mag.: 500 diams.
Etched: Picric Acid.
Remarks: Fine grains of Austenite with considerable amount of free tungstede. (White globules.)



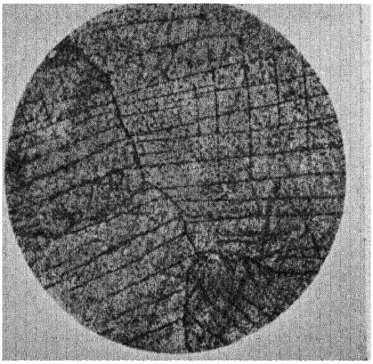
Spec.: Machine Gun Mechanism.
Illum.: Vertical.
Camera: 78 cms. Obj.: 4 mm.
Ocu.: Projn. Mag.: 500 diams.
Unetched.
Remarks; File mark in radius at bottom of extractor stop.



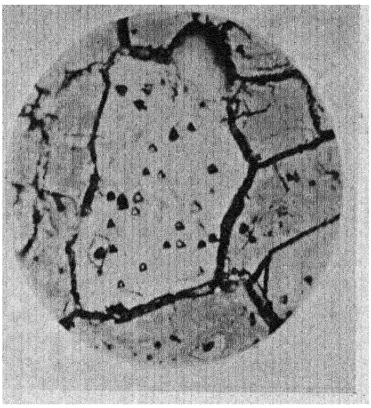
Spec.: Machine Gun Mechanism.
Illum.: Vertical.
Camera.: 61 cms. Obj.: 2 mm.
Ocu.: Projn. Mag.: 1,000 diams.
Unetched.
Remarks: File mark in radius deflected alongside slag patch.



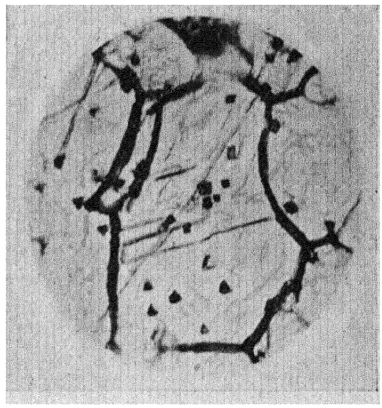
Spec.: Machine Gun Mechanism.
Illum.: Vertical.
Camera: 92.5 cms. Obj.: 2 mm.
Ocu.: Projn. Mag.: 1,500 diams.
Etched: Picric Acid.
Remarks: Strain in structure round crack in .50% C. steel. Troostitic condition.



Spec.: B. Brass.
Illum.: Vertical.
Camera: 55 cms. Obj.: 4 mm.
Ocu.: Projn. Mag.: 250 diams.
Etched: Ammonium hydrate.
Remarks: Shows junction of three crystal grains. Each with own system of slip bands.



Spec.: Nickel Rolled Bar.
Illum.: Vertical.
Camera: 92.5 cms. Obj.: 2 mm.
Ocu.: Projn. Mag.: 1,500 diams.
Etched: Nitric Acid.
Remarks: Etching pits in nickel crystals.



Spec.: Nickel Rolled Bar.
Illum.: Vertical.
Camera: 92.5 cms. Obj.: 2 mm.
Ocu.: Projn. Mag.: 1,500 diams.
Etched: Nitric Acid.
Remarks: Twinning plane in nickel crystal with resulting difference in orientation.

SUGGESTED IMPROVEMENTS IN THE METALLURGICAL MICROSCOPE

By Professor H. Le Chatelier (*Paris*).

The writer has for some considerable time been endeavouring to extend the use of the Microscope in Metallurgical Works. No one to-day will contest the services that Metallography renders to Industry, and it is possible that the sphere of usefulness of this method of investigation could be still further extended by improvements in detail.

The object of this brief note is to point out two possible improvements.

In the first case, to obtain good photomicrographs the use of apochromatic objectives is necessary. These are very costly and many workers hesitate to incur the expense of providing them. Would it not be possible to persuade Manufacturers to design Objectives corrected for some single wave-length of the spectrum ?—viz., the blue line of the Mercury Vapour Lamp, which is easily separated from the other rays and which moreover has a considerable actinic effect. Such simple objectives in which it would only be necessary to take into account corrections for spherical aberration could be manufactured as a single lens and would thus be comparatively cheap.

The second improvement, which it is desirable to introduce into an objective used for the examination of metals is to give to the radius of curvature of the back surface such a value as to prevent concentration of the light reflected from this surface. In all Metallurgical Microscopes illumination must necessarily be effected through the objective. This is a new condition and consequently one complication more in the construction of objectives, but perhaps it may not be insuperable.

From an entirely opposite point of view it would be very useful if a small handbook were drawn up for the use of those who employ the Microscope, as well as for a few of the Manufacturers, such a manual explaining the essential properties of the instrument. Every day the grossest errors are made in this connection. A great number of experimenters imagine that a Microscope Objective can be used like a thin lens. They forget that every objective is constructed to give an image at a fixed point, this being 16 or 25 centimetres according to the country of manufacture. We frequently see photographs taken with a Microscope objective, in which the adjustment (tube length) is changed so as to project the image a greater or lesser distance according to the magnification it is desired to obtain. Now, on the contrary, the extension of the Microscope should always remain invariable and a projection eye-piece used for taking the photomicrograph. The distance of the two lenses of this eye-piece should be adjusted according to the magnification desired.

Another practice which should be no less condemned when using the Metallurgical Microscope is that of reflecting the luminous pencil at right angles by means of a total reflection prism placed in the path of the pencil of light, instead of employing a silvered reflecting mirror. The former method completely changes the working of an objective by making the pencil of rays pass through a piece of glass many centimetres thick. The objective is calculated for working in air and not in glass.

These errors are not very important when the examination is simply by the naked eye, because the eye has an extraordinarily high degree of accommodation. This, however, is not the case in photography. Frequently the sharpness of image that ought to be possible where objectives are properly used is far from being obtained.

To sum up: hitherto Microscopes have only been seriously investigated for the examination of transparent objects and it would be highly desirable if this study could be resumed and extended with a view to the examination, by reflection, of polished opaque bodies like metals.

SUGGESTED ALTERATIONS IN THE DESIGN OF THE LE CHATELIER TYPE OF METALLURGICAL MICROSCOPE.

By PROFESSOR F. GIOLITTI (*Italy*).

It is well known that the principles laid down by Le Chatelier for the design of his instrument have been applied, with different constructional details, by various Makers and it is also recognised that the design of the Le Chatelier Microscope which has found greatest favour is that adopted by Pellin of Paris and Dujardin of Düsseldorf.

I have had long and practical experience of this latter type of design, and I do not think I am wrong in stating that, even though the Le Chatelier Microscope offers the best solution of problems connected with the microscopic examination of metals, and is much preferable to all similar types of apparatus on the market, it has two disadvantages, which, however, are quite easy to rectify by means of some simple modifications in constructional detail.

The first of these disadvantages consists in the fact that the rack which supports the stage is directly fixed " on one side " of the stage, so that the weight of the stage and of the object placed upon it tends to produce a sagging of the rack.

This sagging effect becomes more and more pronounced as time goes on, and prevents the focussing of the whole of the metallic section under examination. It is intensified, and in a short time may seriously damage the instrument when it is required to examine fairly heavy specimens, and this is a case which frequently occurs in practice.

The second disadvantage consists in the absence of an apparatus, which, like the revolving objective holder in the ordinary Microscope, permits of rapidly and easily changing the objective. In the Le Chatelier instrument, in order to change the objective, it is necessary to raise the stage, unscrew the first objective, screw the second objective into the place of the first, lower the stage, and refocus. This operation is very long and tedious, and it is even more so when, with a view to preventing the inconvenience of allowing the various objectives to remain uncovered on the work table, it is necessary each time to put back into its case the objective which has been removed from the Microscope and take out of its box and fix on the instrument the new one required. And, of course, it is often necessary to examine each metallic section under various magnifications, in order to find out with accuracy the true significance of the various structural elements, and eliminate errors in the interpretation of the structure.

For these reasons I have studied, with the help of Dr. A. Filippini of Genoa (to whom I extend my heartiest thanks for his valuable collaboration), a type of Microscope which, while still preserving the extremely useful fundamental principle of the " vertical " observation which makes the Le Chatelier Microscope so practical, gets over the disadvantages to which I have referred.

The new Instrument differs from similar apparatus principally by the addition and different arrangement of a few of the external parts, which are clearly shown in the illustration, Fig. 1.

I will, therefore, only refer very briefly to the features of these parts, without touching upon anything regarding the other components of the Microscope—such as method of illumination, system of projection, etc.—which do not differ essentially (except for the special

design rendered necessary owing to the new type of construction) from the corresponding parts of other similar apparatus.

As is clearly shown in the illustration, in the new instrument I have endeavoured to eliminate the first of the two disadvantages mentioned, by supporting the stage by a bar fixed to it at two opposite points. The bar is, in its turn, supported by the rack, the axis of which coincides with the perpendicular of the stage, carried through the centre of the stage itself. It is evident that in this way the defects due to the sagging of the rack are eliminated, provided care is taken in centreing the objects to be examined in the middle of the stage.

In the instrument constructed by Messrs. Reichert it is possible to support on the stage specimens weighing several kilogrammes, without any appreciable deviation from the normal between the optical axis and the plane of the polished surface resting on the stage.

Owing to the frequency of cases in which in practice it is necessary to place very heavy objects on to the stage, I have thought it necessary to take the weight of the object off the fine focussing micrometer screw, by fixing—as will be seen in the photograph—the screw itself to the slide which carries the tubes of the visual and projecting eyepieces. The result is that the coarse movements and approximate focussing are effected by moving the stage, while the comparatively delicate movements required for very fine focussing are made by manipulating the eyepiece tubes. It will be recognised, owing to the smallness of the movements necessary to bring the objects into correct focus, that such a modification does not detract from the proper illumination of the object.

I have overcome the second disadvantage mentioned by adding to the microscope a proper revolving holder for 4 objectives. The use of the revolving holder offers some difficulties in this case; both owing to the necessity for fitting it in such a way as not to hamper the various functions of other components of the instrument, and with a view to preventing any modification in the characteristic dimensions of the objectives by deviating from those which give the best results in the examination of opaque metallic specimens illuminated by reflected light. The first difficulty has been overcome by replacing obliquely the bar which supports the stage, in the manner shown in the photograph. The second difficulty has been eliminated by giving to the revolving objective holder the special shape represented in the same illustration.

The above description refers to the design of instrument for visual observation. The complete apparatus as used for Photomicrography is shown in Fig. 2.

In addition to the advantages mentioned above, the new Microscope offers still another—not indispensable—of permitting the oblique illumination of the specimen examined with the low power objectives. The adjustment for oblique lighting, which already existed in the Metallurgical Microscope designed by Martin, had to be abandoned, from considerations of manufacture, in that of Le Chatelier, but it has been satisfactorily applied in the new instrument, thanks to the special design of its essential parts.

For the reasons already referred to, it is unnecessary for me to describe the new instrument in more detail. I would only add that in practical application the features of design which I have briefly outlined above have shown themselves to be extremely useful.

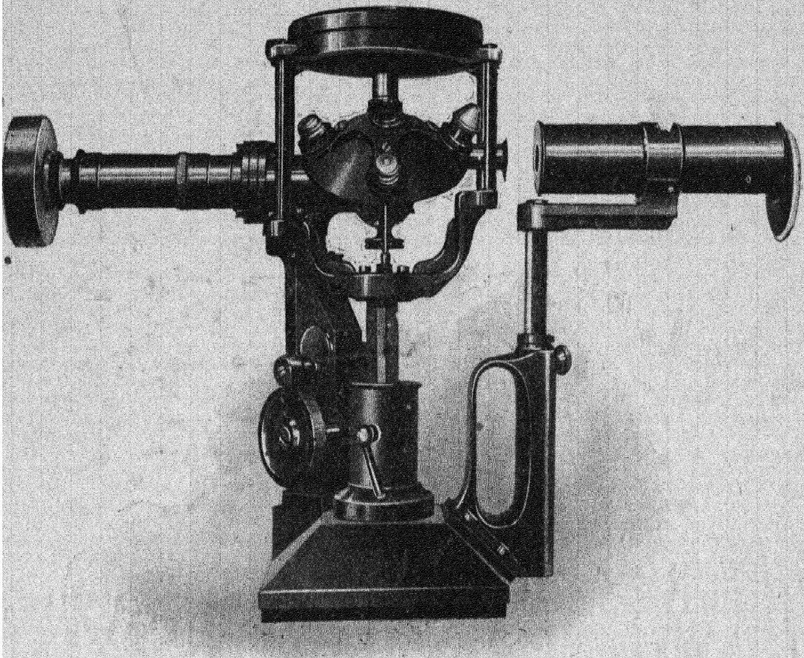


FIG. 1.

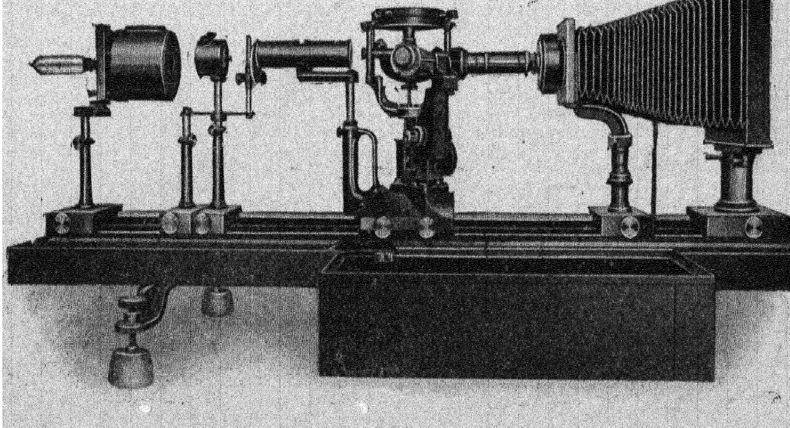


FIG. 2.

IMPROVEMENTS IN METALLURGICAL MICROSCOPES.

By Albert Sauveur (Harvard University).

At the kind request of Sir Robert Hadfield, I am submitting this slight contribution to the symposium on the microscope and its applications. Referring first to the minor improvements I have been able to introduce into the construction of metallurgical microscopes, I venture to mention the following points.

It is, I believe, at my suggestion that microscopes for metallurgical work were first constructed by the Bausch and Lomb Optical Company, of Rochester, New York, with a stage that could be racked up and down in a manner similar to the substage attachment, thus affording greater working distance, and doing away with the necessity of ever having to displace the vertical illuminator, the condensing train and the source of light as objectives of varying focal lengths are used. It is also at my suggestion that in inverted microscopes and in the vertical-horizontal type herewith illustrated a totally reflecting prism was attached to a horizontal draw tube, affording a ready means of pushing it in or drawing out of position as desired.

The two types of metallurgical microscopes used almost exclusively in the United States are shown in Figs. 1 and 2, special attention being called to what may be called the horizontal-vertical type (Fig. 1), in which a vertical microscope is used for visual work, while a permanently connected horizontal camera is used for photographic work. It is believed that this arrangement presents some decided advantages over the vertical type as well as over the inverted type. I do not believe that these instruments have ever been surpassed by those of German manufacture.

The magnetic holder which I designed many years ago for holding iron and steel specimens has proved, I believe, very serviceable, and is widely used in the United States.

As to the directions in which metallographic investigation should be stimulated as more likely to bring valuable results, I am not one of those who believe that much is to be expected from examination at greatly increased magnifications. Confining my remarks to iron and steel, with the exception of the occurrence of carbon, we are still greatly handicapped by the lack of methods by which other constituents and impurities can be identified and their occurrence studied, and it seems to me that we should endeavour to remedy this condition. Let us briefly consider the various elements or chemical compounds present in industrial iron-carbon alloys.

Carbon.—We have at our command satisfactory means of distinguishing under the microscope the various forms in which carbon occurs in these alloys. I am not of the opinion that carbon may be present, as some believe, in a much greater number of varieties than we are now able to identify, and I do not believe that examination under greatly increased magnification or other methods would advance much further our knowledge of the behaviour of that vital

element. Carbon is present in iron-carbon alloys either as graphite, or as the carbide Fe_3C, which may be free or which may form with iron a solid solution. I am not attempting at present to distinguish between solid solutions and colloidal solutions or emulsions. I believe that the hardening of steel is due to the retention of the carbide Fe_3C in a solid solution, but I also believe that the solution thus retained by rapid cooling is allotropically different from the solid solution stable above the thermal critical stage.

Phosphorus.—It is believed on good grounds that phosphorus exists as Fe_3P in iron, but unless there is a considerable percentage of carbon present one cannot under the microscope detect the presence of that compound, owing to the fact that it forms with ferrite a solid solution. A method by which steel high in phosphorus could be differentiated under the microscope from one low in phosphorus would be of great service. To be sure, it is believed that segregation of phosphorus may be detected by the Stead's reagent or by similar reagents, but in the light of recent research we are in doubt whether the segregation which we have been in the habit of attributing to the occurrence of phosphorus may not be due in some cases to the presence of some other element or elements, for instance, to the presence of oxygen. Obviously better means of identification are needed.

Sulphur.—We have satisfactory ground for our belief that sulphur in steel unites with some of the manganese present to form particles of manganese sulphide distributed somewhat irregularly in the metal, and that it may also form a sulphide of iron. These can be detected quite readily under the microscope. It is not certain, however, that the dove-coloured inclusions generally assumed to be manganese sulphide contain no other constituents, nor do we know positively that sulphur forms no other compound and that it is not present in any of the other constituents detectable under the microscope.

Manganese.—We believe that some of the manganese present in steel forms, as stated above, manganese sulphide, as well as manganese carbide, and also that some of it is present in solild solution in iron, but with the exception of manganese sulphide it is not possible to detect the presence of manganese in any of its other forms under the microscope.

Silicon.—Silicon is generally supposed to be present as an iron silicide dissolved in iron. It is not possible, however, to verify by the microscope the accuracy of this belief.

Special Elements.—Microscopical evidences of the form in which special elements, such as nickel, chromium, tungsten, vanadium, etc., occur in steel are lacking.

I believe that the discovery of etching or other methods that would permit a more thorough and more exact microscopical analysis of iron and steel and of their inclusions would be of great assistance in the further development of metallography.

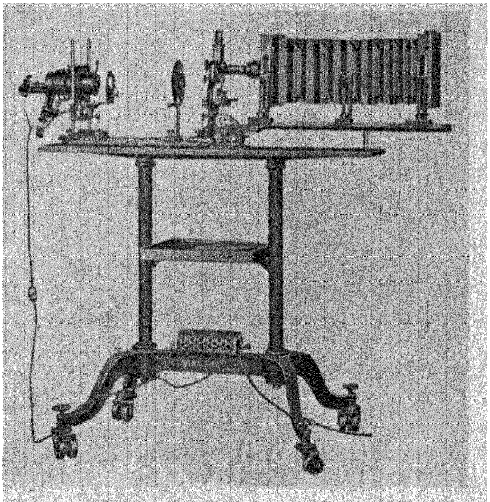


FIG. 1.

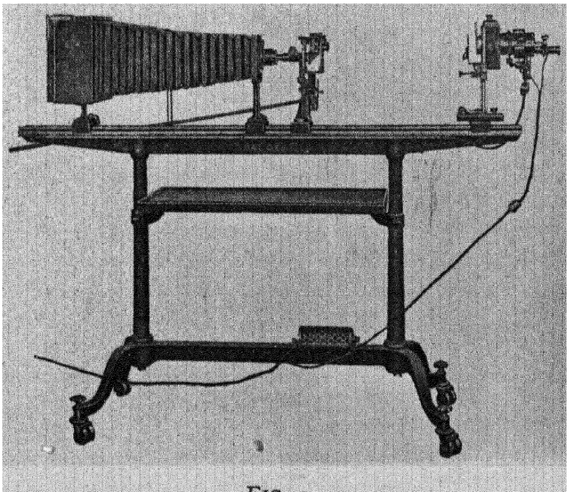


FIG. 2.

SOME POINTS CONCERNING SHARPNESS IN HIGH MAGNIFICATION MICROGRAPHS.

By Carl Benedicks and Erik Walldow (University of Stockholm)

1. *Microscope and accessories used.*

The following will give a short account of some optical studies executed by us, using the new-constructed metallographical microscope of C. Reichert of Vienna.

The most prominent feature of the new microscope, which is constructed according to the Le Chatelier type, is the very convenient interchangeability of the plain glass illuminator and the prism illuminator. This interchangeability was introduced in consequence of a short paper by one of us,* in which evidence was given of the superiority of the former illuminator at high magnifications. Another innovation is the very convenient adjustment, with index and scale, of the position of the prism—which is of the Le Chatelier type, with two reflecting surfaces—so as to enter more or less, according to the focal length of the objective.

Another detail of the construction is, that the coarse adjustment is operated by a rack and pinion motion of the stage on which the specimen rests (face downwards), whilst the fine focussing is obtained by a micrometer slide motion of the objective and tubes. The advantage is, that a heavy weight on the stage will have no influence on the delicate slide motion.

For photographic work, a green glass filter was used, giving a rather well-defined wave length of 0.5-0.6 μ. Orthochromatic plates (Wellington, anti-screen, backed) were used, and an arc lamp of about 350 c.p., the duration of exposure was increased by this filter in the ratio 10:1. The regular exposure (with filter) was 20 secs. when the glass slide illuminator, 4 secs. when the prism illuminator, was used.

The test specimen was a lamellar pearlite of 0.90 per cent. carbon content, polished in bas-relief on parchment.

2. *Arc lamp and incandescent lamp.*

Fig. 1 gives the specimen at a magnification of 1,200 (arc lamp; immersion apochromatic f = 2 mm., Num. aperture 1.30; projection eye-piece Nr. 2; camera length 65 cm.).

In Fig. 2 a "Half-Watt" incandescent lamp of 60 c.p. was used; of course, several advantages are obtained by a less intense source of light. The exposure had to be prolonged 36 times, to 12 min.

The optical quality of Fig. 2 is still good, but the definition is impaired by a general want of sharpness due to vibration during the long exposure.

It must be pointed out, however, that under quieter conditions photographs were obtained with the incandescent lamp of the very highest sharpness, which in no respect differed from Fig. 1. This proves that the *candle power of the lamp has no influence on the image quality*—a point which, though very natural, scarcely has been proved so far as yet.

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* C. Benedicks, *Metallurgie,* Vol. 6, p. 320, 1909.—Dr. W. Rosenhain made some remarks in the same direction in *J. Iron and Steel Inst.,* 1906, II, p. 180 (*see Metallurgie,* Vol. 8, p. 136, 1911).

The mirror reflecting arrangement provided with the camera proved to be of value, especially at long exposures, as it provides the possibility of a control of the proper focussing during a long exposure, without having any disturbing effect.

3. *Influence of vibrations and its avoidance.*

Even at short exposures with the arc lamp the sensitiveness for vibrations is very undesirable. The whole instrument being very rigidly constructed, the cause of this sensitiveness was by no means obvious. After a detailed examination, it was found that the comparatively great mass of the tube-carrying upright, with the two tubes (ocular and photographic), illuminator and objective, was responsible for the vibration sensitiveness. The remedy was possible to indicate: the objective is to be mounted by itself, on a special upright with little mass, and must have no direct connection with the tubes; if this be the case, then the inevitable vibrations of the tubes will be of no direct influence on the distance between objective and specimen—which is the most sensitive point as regards sharpness. A slight disadvantage introduced by this modification is that the distance between the illuminator and the objective will be subjected to small changes; these, however, seem to be of little consequence in comparison with the considerable increase in insensibility to vibrations which probably will result. Of course, even in works laboratories it is important to be able to produce good high magnification photographs without too much trouble.

In this connection the following may be added.

If the ground of the laboratory is not sufficiently free from disturbance it is necessary to mount the apparatus on some vibration-damping device. Now, it has been found from investigations executed in this laboratory by I. Malmborg* that the simplest thing is to mount the instrument on a solid plate, resting on a thick layer of felt; this, however, must not, as is ordinarily the case, be used in a dry condition, but moistened with a viscous liquid, such as vaseline. The energy of the disturbances is then absorbed through the forced motion of the liquid in the interstices of the felt. This method has been used with great advantage.†

4. *Disposition of diaphragms.*

In the metallographic microscope the cutting off of side-rays by diaphragms is well known for several reasons to be of great importance. As a general principle it can be said that the beam of light is to be reduced as much as possible without interfering with the intensity and uniform distribution of the light, or with the necessary extension of the image.

Fig. 3 gives diagrammatically the illuminating arrangement. In order to work properly, the image of the source of light—as which the opening of the diaphragm B is to be considered—must fall on, or at least near, the illuminator P, and the image of the iris diaphragm I must fall on the surface of the specimen T. The first item, brought about by the lenses L and F, is necessary in order to be able to use the whole of the light power available, and

* *Ann. d. Physik* (4), Vol. 44, p. 337, 1914.

†Benedicks, *J. Iron and Steel Inst.* 1914. I, *p* 407 (424).

to obtain a systematic centering of the light; the second item, effected by lens F and objective O, is necessary in order to limit properly the image on the plate, and to cut off false light so far as possible.

There is, in our view, no reason why the parts of this optical system should be differently arranged (sliding of L) when using a plain glass reflector or a prism reflector; nevertheless, on the microscope examined, as well as on other Continental microscopes, such a difference has been introduced intentionally. As a matter of fact, it was found quite practicable to obtain correct results, so far as the illumination is concerned, with both kind of reflectors, without any variation in the position of L (lens F had to be changed).

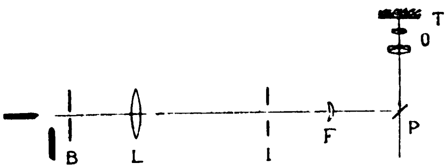


FIG 3

5. *Comparison between Le Chatelier prism and 45° prism.*

The Le Chatelier prism being so constructed that the lens F is formed in the same piece of glass as the reflecting surface P—which, in fact, is made up of two planes giving successive reflection—it was to be expected that it would produce sensibly better contrasts than a 45° prism with separate lens F, as in this case more reflections must occur.

A careful comparison was carried out. The result was that it was not possible for us to trace any difference in the working of the two kinds of prisms: the 45° prism is practically, so far as contrasts are concerned, not at all inferior to the Le Chatelier prism.

All comparative experiments were so made, by a special projection arrangement, that both prisms (or metal mirror) were exactly in the same position, covering the half of the back lens of the objective.

It was found that for lower magnifications than with the apochromatic f = 2 mm., the Le Chatelier prism has a decided advantage over the 45° prism in so far as it is not necessary, for obtaining a uniform illumination, to cover so much as half of the light area with the Le Chatelier prism as with the 45° prism. Thus at lower magnifications the aperture is better utilised with the Le Chatelier prism. The arrangement mentioned above serves the purpose of easily obtaining for each objective the proper position of the prism.

6. *Influence of the aperture.*

As already remarked, it has been pointed out by Dr. Rosenhain and by one of the present authors that the definition of the image at high magnification is considerably lessened when half of the aperture of the objective is covered by a prism or by an opaque

mirror, the resolving power being reduced to one-half in the direction at right angles to the mirror edge.*

This fact is amply borne out by our new comparative experiments. Thus, Fig. 4 shows the very best definition to be obtained with a prism illuminator. A comparison with Fig. 1, which was obtained with the plain glass illuminator, gives evidence of the much higher quality of the image obtained in the latter case, thus laying stress on the fundamental condition for obtaining sharp high magnification micrographs: the *full utilisation of the aperture of the objective.*

7. *Comparison between prism and metal mirror.*

It is obvious that with reflecting glass prisms—as well the Le Chatelier as the 45° prism—inner reflections cannot be entirely got rid of. On the other hand, with a metal mirror, such undesirable reflections do not occur, and it is to be expected that the contrasts will improve.

As the result of some direct comparisons, it was actually found that an indisputable, though slight, increase of the contrasts was to be seen on the micrographs obtained with the metal mirror. Thus, a metal mirror illuminator may be of some use whenever particularly strong contrasts are desired.

8. *Influence of the thickness of the plain glass.*

The glass slide provided with the microscope used was 0.45 mm. thick. It may be questioned whether this thickness, on account of the astigmatism introduced, is not too high. On using a very thin glass, 0.10 mm., as a matter of fact, a slight improvement of the sharpness occurred; this, however, was so insignificant that practically the use of the thicker glass must be considered to be quite justified.

If one is at liberty to choose, a thinner glass, of course, should be preferred to a thicker.

9. *Astigmatism introduced by the right angle reflecting prism.*

It seems by no means excluded, that sensible astigmatism could not be introduced by the right angle prism used in the Le Chatelier microscope in order to reflect horizontally the vertical beam of light issuing from the specimen. However, the excellent definition obtained, as in Fig. 1, shows that this undesirable influence of the prism can be entirely neglected. Of course, it is essential that the prism be of a very high optical finish, and carefully adjusted.

10. *Platinised plain glass illuminator.*

As pointed out on an earlier occasion,† it might be possible to increase the light intensity obtained with the plain glass illuminator by using a thin silver or platinum coating. Obviously, the thickness of the metal layer must not exceed a definite value; otherwise a decrease of intensity will result.

* *See* for instance Dr. Rosenhain's *An Introduction to the Study of Physical Metallurgy,* London, 1914, p. 52.

† C. Benedicks, l.c.

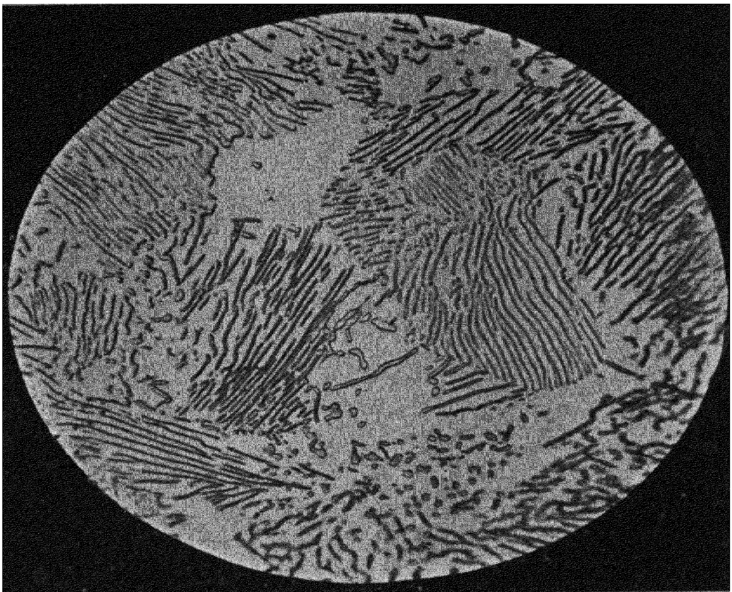
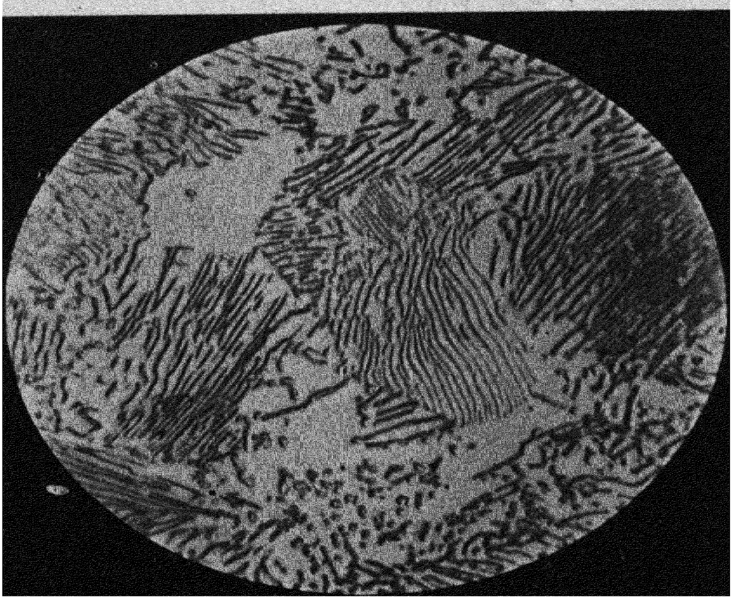


FIG. 1.
Plain glass illuminator, Arc lamp ; 20 secs. × 1200



Plain glass illuminator, " Half-Watt lamp " ; 12 mins. × 1200.

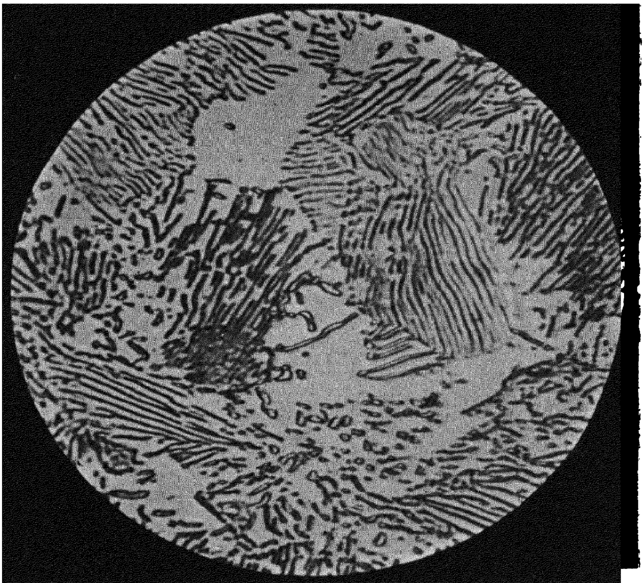


Fig. 4.
Le Chatelier prism illuminator, Arc lamp; 4 secs. × 1200

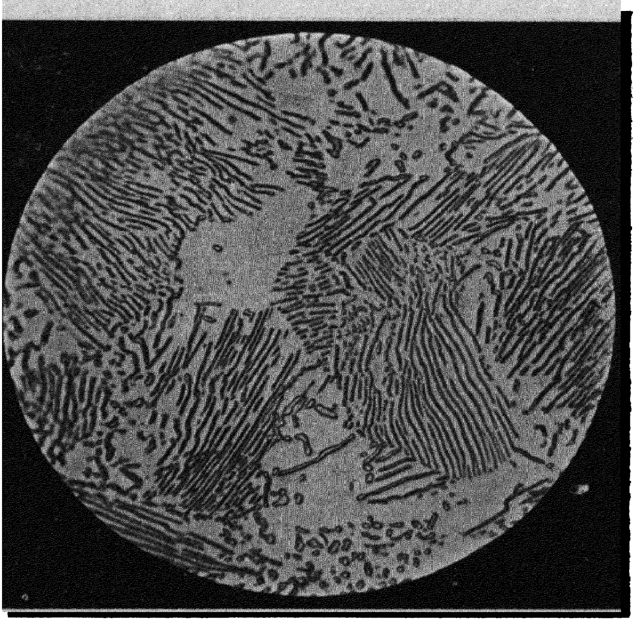


Fig. 5.
Plain glass platinised, Arc lamp; 20 secs. × 1200

Fig. 5 reproduces a micrograph obtained with a platinum layer of a definite thickness, scarcely providing any appreciable increase in light intensity; exposure 20 secs., as in the other cases. A somewhat thinner coating might have been desirable.

It is of interest to note, however, that the micrographs obtained in this way were characterised by an unusually large extension of the sharp image. The contrasts seem to be somewhat weaker than those obtained with the other illuminators, and possibly this is the reason why on Fig. 5 (in original) are to be seen details, *e.g.*, some characteristic irregularities in the ferrite ground mass, which scarcely are to be seen on any other of the micrographs taken.

Thus it was found from these experiments that any essential gain in light intensity is difficult to obtain by platinum coating, but on the other hand a more detailed investigation is required to find out whether the filtering of the light on passing through the thin metal coating might possibly be of some advantage when it is a question of bringing out a maximum of detail.

11. *Further remarks.*

It has to be added that every exposure was repeated several times, and found consistent with similar experiments, so that, notwithstanding the obvious difficulty of avoiding focussing errors, the results obtained appear to be quite reliable.

A detailed account of these investigations has been published in Swedish in *Bihang till Jernkontorets Annaler*, Vol. 19, p. 537, 1918.

A detailed account will also probably appear in *Zeitschrift fur Wissenschaftliche Mikroskopie.*

Summary.

The investigations were started as a detailed and critical examination of the new Reichert microscope, which is of the Le Chatelier type. It was found to produce excellent results at the very highest magnifications.

Then some points of a more general character were examined, as:

(1) The using of an arc lamp (350 c.p.) or of an incandescent lamp (50 c.p.) gave exactly the same result.

(2) A modification of the microscope is proposed in order to diminish its vibration sensitivity.

(3) The proper arrangement of the diaphragms is discussed.

(4) A Le Chatelier prism and a 45° prism give at high magnification exactly the same result.

(5) A metal mirror gives slightly better contrasts than a prism.

(6) In the plain glass illuminator a thickness of 0.45 mm. does not injure sensibly the image quality.

(7) A slightly platinised glass illuminator gave somewhat finer details than any other illuminator used; this question, however, needs further research.

AN ORDINARY MICROSCOPE ADAPTED TO METALLOGRAPHY.

By F. Ian G. Rawlins, F.R.M.S.

The purpose of the following brief note is to draw attention to certain details of a more or less minor nature, which, when incorporated into an ordinary microscope stand, render it decidedly efficient for metallographical work, where an elaborate outfit is not desired. Although post-war models are now appearing by the leading makers for this branch of microscopy, there is a decided advantage in being able to use an ordinary stand, and the expense involved in the modifications is very moderate. Lastly, the additions are such that they can be easily carried out, even in the present abnormal state of the trade; and they are no detriment to work on transparent objects.

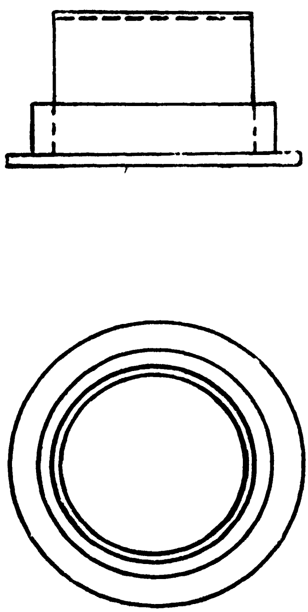


FIG. 1.

Vertical and Horizontal Sections of Plug.

(1) *Substage Fitting.*

The point of this is to overcome the trouble inherent in the use of ordinary stands for opaque objects with the vertical illuminator, *i.e.*, that on re-focussing, the centering of the illuminator and light source is disturbed. Assuming that the stand possesses no substage apparatus (apart from the mirror), a focussing substage is fitted, provided with coarse adjustment, rack and pinion. Instead of the usual condenser, a solid brass plug (circular, and of the shape

sketched in vertical section,) is inserted into the ring. The top is provided with a slightly bevelled edge, into which fits a glass slip on which the plasticine holding the specimen is placed as usual. This can then be focussed upwards and downwards, avoiding any movement of the body-tube. To substitute another specimen, all that is needed is to rack down, swing the fitting out of the optic axis, take out the plug, insert another levelled specimen as already described, re-insert the plug, and focus as before. Of course, if only objectives are being changed, the focus can be re-set at once. An adapter fitted to the body-tube may be wanted if the rackwork on the stand is limited. The central aperture in the stage is generally too small, and should be enlarged for these additions. In the event of transparent work with condenser, polariser, etc., being contemplated, the focussing substage is ready at hand, the appropriate fitting being substituted for the afore-mentioned plug.

(2) *Objectives.*

Mounting in short barrels is very desirable for use with the vertical illuminator. There is often considerable difficulty in obtaining objectives so arranged from the makers. The following alteration, easily carried out, may assist. The lower part of the barrel is

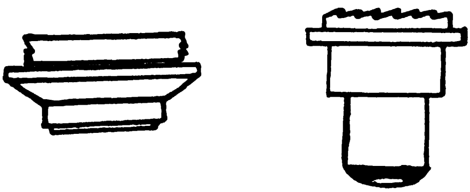


FIG. 2.
Carrier and Unscrewed Part of Objective.

unscrewed, and then inserted into a carrier bodily, which latter is provided with a standard thread, attaching to the vertical illuminator, and bringing the back lens of the objective very close to the reflector. Two lenses so treated, a $\frac{1}{3}$ inch and a $\frac{1}{6}$ inch, in the writer's possession give excellent results in practice.

(3) *Illumination.*

A type of "Half-Watt" lamp made in Holland has been found admirable. The 200 candle-power size is amply sufficient. By noting that the ring-filament in these lamps gives a very solid and concentrated area of light, and using a bull's-eye condenser of small aperture, it is possible to get effects closely resembling a "point-source" of light. The very moderate cost of these lamps compared with, say, a "Pointolite," is greatly in their favour, and they are quite powerful enough for magnifications up to 600 diameters in metallography.

In conclusion, apart from general ideas, the author disclaims any question of having originated the above improvements. His thanks are due to Messrs. H. F. Angus and Co. for their skilled assistance.

THE MICROSCOPE IN METALLURGICAL RESEARCH.

By E. F. Law.

It would be difficult to over-estimate the importance of the part played by the microscope in metallurgical research during the last 15 years. Its introduction threw a flood of light on problems hitherto unsolved, and it was not surprising that the early work of the pioneers—Sorby, Osmond, Roberts-Austen and others—was followed by a rush of eager recruits anxious to take part in the campaign. Nor was it surprising that this display of zeal should be followed by a lull, if not an actual reaction; such periods invariably follow a period of exceptionally rapid progress, and when they occur it is wise to take stock of the existing position and endeavour to prepare the way for the next advance. With that object in view we may briefly consider the metallurgical problems which have already been solved by means of the microscope, and then turn to some of those which are awaiting solution and which require either more knowledge or more perfect instruments.

Problems Solved.—Before the introduction of the microscope we knew from the chemical analysis of an alloy its ultimate chemical components, but we did not know in what form those components occurred. Probably the only exception to this rule was to be found in the case of carbon in cast iron, which was invariably divided into free or graphitic carbon and combined carbon. The microscope altered all this, and explained not only the relationship between the structure of the alloy and its mechanical properties, but the structural alterations and consequent changes in mechanical properties produced by heat treatment.

Problems to be Solved.—With very few exceptions, it may be said that the finer or smaller the structure of an alloy, the more useful it is from a commercial standpoint; and it frequently happens that the best of our commercial steels possess so fine a structure that they are imperfectly resolved by the highest powers of the microscope now available. How often do we read in descriptions of microstructures such expressions as "a confused groundmass" or "a matrix whose structure is not resolved by the microscope"? Another problem awaiting solution is to be found in the intercrystalline weakness of metal. During the last few years a wonderful edifice of hypotheses has been erected on the foundation of a so-called amorphous phase which is said to exist between the crystals of a metal, and this amorphous material is made to serve as an explanation either of its strength or weakness.

Unfortunately, there is very little direct evidence in support of these theories; but with a higher degree of magnification it is possible we may learn more of the intercrystalline structure of metals. Even of the crystalline structure we know very little, and there is scope for much research on the "dendritic" structure which is shown on heat-tinting, and which has been so beautifully developed by Humfrey.

For these and other investigations we require instruments which will give us a higher degree of magnification, and we look to the manufacturers for their assistance. But, if we are provided with such instruments, we, on our part, must be prepared to supply a much higher degree of skill in the preparation of samples for examination than is commonly met with.

DEVELOPMENT OF THE METALLURGICAL MICROSCOPE AND ITS SUGGESTED APPLICATION TO SOME UNSOLVED PROBLEMS.

By HERMAN A. HOLZ, NEW YORK.

Every step forward in the development of apparatus for metallurgical research work is followed by an increase of our knowledge of the particular field of metallurgy for which the instrument serves. In other words, suitable apparatus have to be developed to a high stage of perfection before we can make accurate and reliable determinations which enable us to gain valuable knowledge of certain facts which were unknown to us before or about which we were not quite certain.

The development of the thermo-electric pyrometer by Le Chatelier enabled us to find the transformation regions in steel, Sir William Roberts-Austen's apparatus—making use of thermo-electric forces—permitted us to determine these transformation regions with great accuracy and in a convenient manner, resulting in systematic research work which forms the basis of the art of heat-treating steel.

The most important apparatus which enable the metallographist to find the way towards improvements in the structural details of steel and to control the correct thermal treatment to which he subjects the material, are the microscope and the permeameter. The microstructure of steel can be observed and photographed by means of the microscope, while it can be measured and expressed in definite figures by means of the permeameter, thus permitting quantitative determinations. The success gained in recent years in obtaining higher efficiency from definite alloys, especially alloy steels, and in developing steels and bronzes of greater strength, has been due to systematic metallographic, especially microscopic, research work.

As the methods of microscopic investigation have been improved by the development of more efficient etching processes, so have the design and construction of metallurgical microscopes been gradually developed to a high stage, in regard to the quality of lenses, source of light, vertical illuminators, etc., as well as to rigidity and usefulness of mechanical arrangements. While the pioneer work on the microstructure of metals was carried on by means of ordinary (bacteriological) microscope stands, it was soon found that the investigation of opaque substances, without using cover glasses over the object, necessitated changes in the illuminating system and in the grinding and mounting of the objectives. The vertical illuminators now largely used for this purpose were developed in England (45 degree plane glass reflector by Beck) and France (prism reflector by Le Chatelier, first made by Pellin and Nachet). The objectives used in connection with these illuminators have to be mounted as short as possible; the nearer the reflecting surface stands

to the objective, the more even is the illumination obtained. In the method of plane glass reflection, the rays of illumination and of the image penetrate the entire objective simultaneously; the final image suffers somewhat thereby, and does not appear as sharp as with the prism illuminator. This disadvantage can be remedied somewhat by decreasing the opening angle of the objective. The important advantage of the 45 degree plane glass illumination is that the light strikes the etched surface at exactly 90 degrees, so that with the highest magnifications and in working with very fine, slightly etched specimens images richer in detail and free from spectral colours are obtained; the rays of light are, in this case, uniformly distributed over the entire field covered by the objective. In applying the Le Chatelier prism illuminator, one half of the objective serves for illuminating the specimen, the other half for producing the image. This arrangement offers the advantage that by dividing the function of the objective the formation of reflexes is reduced and the full angle of opening of the objective is utilised. The images thus obtained are clearer and sharper, of special advantage in photography. On the other hand, fine details of structure may be lost through the one-sided illumination striking the etched surface at an angle. Since both forms of vertical illuminators possess certain distinct advantages and disadvantages, it will be found very convenient to be able to change quickly from one to the other, and to select the one which will give the more satisfactory image, depending upon the nature of the microstructure under investigation and upon those points that the metallographer desires to bring out more prominently in his micrographs. The latest metallographic outfit brought on the American market by my firm possesses this important feature of "selective" vertical illumination.

Many of the steel works' metallographers prefer now the inverted form of microscope, first designed by Le Chatelier and first made by Pellin. I desire to mention here that the original Le Chatelier-Pellin outfit carried a stage supported on one point only, which was easily bent out of focus, and did not possess sufficient rigidity. Le Chatelier designed in 1911 another and very much improved inverted stand, also made by Pellin, which carries a firmly supported stage and which was imitated by German and Austrian manufacturers. Nevertheless, the largest number of German steel works, amongst them the Krupp works, preferred the new Le Chatelier-Pellin stand which was marketed in 1912 and 1913 with much success in Germany by Dujardin, who imported the microscopes from Paris and fitted them with Zeiss apochromatic objectives, thus combining best mechanical design with good optical equipment.

Returning to the question of metallurgical microscope stand design, I want to say that the popular form of inverted stand really has only the one advantage of eliminating the necessity of levelling the specimen, and this advantage disappears mostly in using an oil immersion lens. The disadvantages of the inverted stand are the limited field which can be observed, the large leverage of the stage resulting in magnification of vibrations, and the impossibility of working with daylight. Microscope stands have been successfully designed (Félix Robin's outfit, formerly made by Collot, Paris), which combine the advantage of horizontal camera with firmly sup-

ported stage below the objective, thus permitting the convenient investigation and photography of heavy specimens, observation of their edges, use of daylight, and large reduction of vibrations. While these outfits are not available any longer, it seems to me that the development of satisfactory photomicrographic apparatus for metallography should follow this general design, and not the inverted design, which possesses several disadvantages more important than its one single advantage.

Amongst other microscopic problems awaiting further development, besides higher magnification, are: the utilisation of polarised light for metallographic investigations and the application of kinematographic work to the study of structural changes in metal sections exposed to mechanical stresses or varying temperatures. The pioneer work in solving the apparatus development problems for these studies has been successfully carried out, and the high value of such investigations will be appreciated. It is to be hoped that research workers will take up systematically this work, which has been successfully started. Further microscope development, offering no more difficulties, will be in the direction of stereoscopy. We are born with two eyes, and used to see with both of them; mon-objective binocular microscopes, for work with the highest magnifications, have been successfully developed, and there seems to be no reason why this instrument development should not be applied to advantage to metallographic practice. I believe that the near future will see a large extension in the use of binocular optical instruments.

I would not like to omit here to mention some important progress made in Great Britain in the development of metallographic equipment: The Edison-Swan "Pointolite" (tungsten arc) lamp, which is the ideal source of light for photomicrographic work, and the Wratten and Wainwright light filters and special plates for photomicrography. These products represent the best that has ever been developed in their respective lines, and every metallographer will find the use of these appliances extremely valuable in his work.

In ending my contribution, I want to make a few additional remarks about the importance of "magnetic analysis" in metallographic research and routine work. The use of higher magnifications in microscopic investigation will most probably lead to valuable results, although we must always remember that the higher we magnify the less we see, *i.e.*, the field of observation is getting smaller with the use of objectives of higher powers. Magnetic analysis (the accurate determination of the various magnetic properties of iron and steel by means of a standard permeameter) enables us to draw distinctions between steels where the present methods (microscopic, hardness, tensile tests) fail to make differentiation. Microscopic investigation of steel gives results which are qualitative, rarely quantitative. The preparation of micro-sections often releases stresses in the metal to be studied, and, in general, tests of this kind require a great deal of individual judgment and experience. Magnetic data permit quantitative measurements of the state of micro-structure and the interpretation of test data leaves no room for conjecture.

Such magnetic investigations can be carried out successfully only by means of a perfectly reliable permeameter and only by determination of *all* the magnetic characteristics of the material under investigation. Permeameter equipment has been recently developed to a high stage of perfection, combining simplicity of operation with perfect accuracy of measurements (Fahy Simplex Permeameter), and since then the application of magnetic analysis to metallographic investigations has made rapid progress in the United States. It is to be hoped that British metallurgists will apply this excellent method to the solution of their problems, and will co-operate with American research workers, to considerable mutual benefit.

General Discussion.

In inviting **Dr. W. H. Hatfield** to offer some remarks on the metallographical side of microscopy, the Chairman suggested that in view of the short time available for general discussion of the many important papers presented on this subject, the discussion be continued at Sheffield, and, if possible, also at Glasgow.

Dr. W. H. Hatfield: I should like to say that I know I should be expressing the general feeling of the Council of the Metallurgical Society at Sheffield in saying that we have great pleasure in accepting your invitation. If you will let us have copies of these papers, particularly the metallurgical section of them, we will have them thoroughly discussed, and, if you desire it, we will send Mr. Spiers a copy of the discussion.

Speaking on the papers, I think one can safely say that we have in Sheffield many large firms who have well equipped laboratories where these different types of microscopes are in use every day. I should like to congratulate the President on the interesting paper by Mr. Elliot and himself. I think that the work contained in this paper typically represents what we are able to do with the microscope in our study of steel. We (Brown-Firth Research Laboratory) have some photomicrographs upstairs; they are really on the same lines as those of Sir Robert Hadfield, but we have gone as far as 8,000 magnifications. I think Sir Robert will probably agree with me when I say that 1,000 diameters really represents the limit of adequate resolution which we are able to obtain in our general practice, and that if we go in for these higher so-called magnifications—I refer both to his illustrations and to ours—we are getting enlarged pictures, but we do not obtain really much more information as to the structure of our materials, and from that point of view it is interesting to refer to the paper on Dr. Sorby which the President has put before us. I notice there that Sorby made great advance in the 'eighties because he was able to use sufficiently high magnification to see the structure of the pearlite. Every time that we have been able to get a still higher resolution we have obtained more fundamental knowledge with regard to steel, and whilst I feel that 1,000 is at present our practical limitation, I am certain that if only you experts in the construction of the microscope can go still further, we shall obtain still more fundamental information. For instance, I remember studying what we know as black steel at 250 to 500 diameters, but we got inconclusive information, but as soon as we got to 1,000 diameters we had definite information and a complete solution of our difficulty. There are two problems which I would like to point out to you microscopists, or rather to the makers of microscopes, which are awaiting solution. One Dr. Aitchison deals with very ably in his paper, *i.e.*, notched bar brittleness. I

will not go into it except to say that there are two fundamentally different conditions of the same steel, which at present we are not able to obtain the reason for by means of the microscope, and I think we have a right to feel that we should. I do not hesitate to make a confession to you. An artilleryman does not worry unduly as to how the gun was made or who made it. I represent exactly that type of scientific investigator who uses a microscope, and, like the artilleryman, I am telling you what we would like to do with the gun. Therefore, I think it is up to the makers of the microscope to help Sir Robert Hadfield and many people like myself who are engaged in these investigations, out of our difficulties. In conclusion, I would tell you that all metallurgists, whether they be working on steel or non-ferrous metals—brass, copper, gold—are faced with the difficulty of obtaining an adequate solution as to the cause of the effect of cold work on metals. We discuss the amorphous theory; many of us believe in it; we ought to be able, by means of the microscope, if you will give us a suitable tool, to obtain an adequate solution of that problem. Why has cold work the great effect it has in hardening metals? Gentlemen, I consider the solution of that problem is awaiting the excellence of your products.

The following contributions have been received to the discussion on the paper by Sir Robert Hadfield and Mr. T. G. Elliot.

Mr. A. T. Adam and Mr. F. S. Merrils: In studying the microstructure of steel wires we have found it necessary to, employ high magnification. The difficulty in resolving the structure of carbon steel wires is due in the first place to the nature of the chief constituent in properly heat-treated wire, viz., "Sorbite," or "Sorbitic pearlite," and secondly to the minuteness of the structure caused by cold work.

Some time ago we were fortunate in securing a very good Leitz 1/12 in. oil-immersion achromatic objective, N.A. 1.3, which has enabled us to obtain sharp photographs of wire up to a magnification of 2,500 diameters. This we have found to be about the highest magnification at which good definition and detail are retained with this objective. In certain special cases we have gone up to about 5,000 diameters with distinct advantage.

One of the contributors, being engaged in an investigation on "The Relation of Heat Treatment to Cold Work," has found these photographs of great service in illustrating the effect of cold work on the structure, and hopes to have them published in the Carnegie Scholarship Memoirs of the Iron and Steel Institute this year.

It is admitted that there is a certain loss of detail in these photographs as compared with visual examination, but this detail is lost in any photograph where an ordinary eye-piece is used. On the other hand, certain features which are barely visible in a photograph at, say, 1,500 diameters, are more pronounced in the enlargement obtained by increased camera length.

In view of these attempts at high power photomicrography, we are therefore extremely interested in the authors' work in this direction, and we are in entire agreement with them in the belief that there is a great field for further exploration in this direction.

One or two examples of photomicrographs at high magnification are given below with details. The source of illumination used is a tungsten arc 500 candle-power "Pointolite," made by the Edison Swan Electric Co., Ltd. With this source of light it is only necessary to use a single condenser to focus the image of the incandescent arc on to the plain glass illuminator. It may be of interest to add that Wratten and Wainwright colour filters, M series, were used with Wratten M Panchromatic Plates in taking these photographs.

Fig. 1 shows that it is possible to obtain good definition in a photograph at this magnification. The subject is possibly not one that requires high magnification in itself, but it is useful for purposes of comparison with subjects that do require such magnifications, *e.g.*, Fig. 3.

Apart from this, it appears to show that "pearlite" is a more complex constituent than lower power photographs indicate. The contributors have always considered the idea that "pearlite" is constructed of alternate layers of ferrite and iron carbide completely

separated, to be rather vague. This photograph suggests that complete separation has not taken place in the laminated form, and occurs only in the spheroidised form; *e.g.*, Fig. 2.

The appearance of sub-laminations in Fig. 1 is not a false effect due to excessive cutting down of the iris diaphragm, as no diaphragm was used in this instance. A slightly false effect, due to this cause, is evident in Fig. 5, which was taken expressly for this contribution.

Fig. 3 shows a subject in which the laminations are too fine to be clearly photographed at a magnification of 1,500 diameters. The photograph demonstrates that even air cooling a rod about $\frac{1}{4}$ in. diameter is not sufficiently rapid to arrest the partial production of "pearlite." It will be noticed that the constituent which we have called "sorbitic pearlite" is partly cellular.

The difference between these structures is not apparent at lower powers.

Fig. 4 is to be compared with Fig. 5. In spite of the slightly false effect in the latter, caused by the iris diaphragm, it draws attention to the existence of a feature which might easily escape notice, but which is apparent on closer examination, in Fig. 4, namely, the sub-laminations.

Mr. Henry M. Sayers: These photomicrographs of steel at 5,000 and 8,000 diameters are very fine, and testify to the skill and patience of the authors. They confirm the accepted theory that no new details can be revealed by magnifications incommensurate with the N.A. of the objective. With an N.A. of 1.4, 1,000 diameters shows all that can be seen, but, of course, greater amplification may be useful for diagrams to be displayed to large numbers of people, at once, just as lantern slides are magnified by projection.

The authors state that the illuminant used was a 20 ampere alternating current arc, the arc being focussed on the stop or aperture of the vertical illuminator. Presumably one or other of the carbons was so focussed. This adds to the merit of the work, for certainly an A.C. arc is less satisfactory in intensity and form of the radiant than a C.C. arc crater.

It will probably be found that one of the larger tungsten arc lamps is better than an A.C. arc. It is true that the tungsten arc requires continuous current, but this can be got from an A.C. supply with a simple form of auto-transformer and rectifier. A nominal 100 c.p. Pointolite, taking about $1\frac{1}{4}$ amperes, gives satisfactory negatives of steel with 5 minutes' exposure, at 1,200 diameters, using a light filter denominated "5 times," and Wellington "Anti-Screen" plates.

The Pointolite lamp is somewhat more convenient for the necessary source emplifying lens system than an arc. The exposures above mentioned were taken with a combination which magnified the source about three diameters, giving a field of 3 in. diameter, *i.e.*, comfortably filling a quarter plate. With no amplifier the field on the plate was only about 1 in. diameter. Greater amplification can be obtained if required by varying the lens distance of the combination.

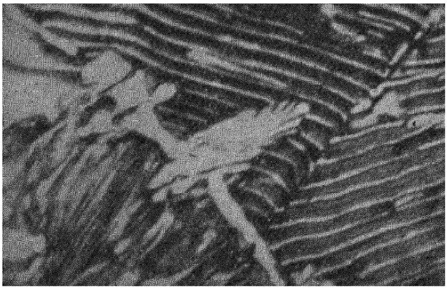
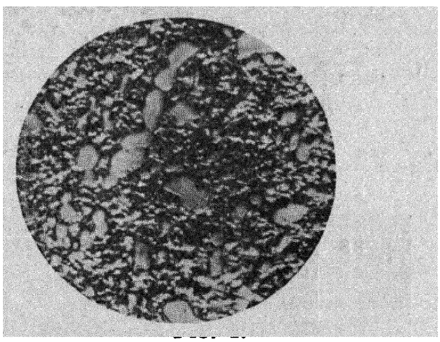


FIG. 1.

1.2 per cent. Carbon Steel, annealed. Magnification 5,000 diams. approx. K.1 Colour Filter.



1.2 per cent. Carbon Steel Wire. Re-heated at 650° C., showing Spheroidised Cementite. Magnification 4,000 diams. approx. Red Colour Filter A, showing maximum detail.

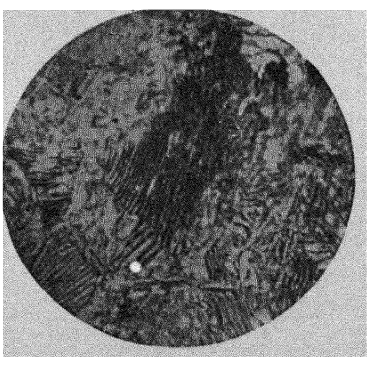


FIG. 3.

900° C., showing Sorbitic Pearlite. Magnification 3,000 diams. Orange 0.85 per cent. Carbon Swedish Steel. No. 5 S.W.G. Rod. Air-cooled from Colour Filter G.

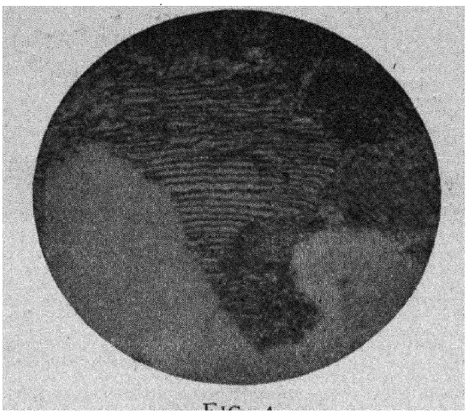


FIG. 4.

0.5 per cent. Carbon Steel Bar, annealed. Magnification 1,500 diams. Red Colour Filter A.

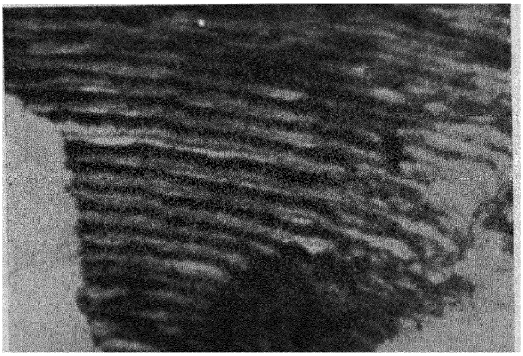


FIG. 5.

Portion of same field. Magnification 4,500 diams. K.1 Colour Filter.

NOTE.—These reproductions have been reduced by one-third from the original photographs.

Professor H. M. Howe (*communicated*).

All our present conceptions of the nature of alloys are due to the microscope. The labours of Sorby, of Osmond, and of Le Chatelier, brought us to the point at which we recongise pearlite as an eutectoid, the great turning point in the progress of our conceptions.

One finds important problems solved quickly and surely by means of a magnification of 2,000 which completely baffled us when our magnification was confined to 200 diameters. Thus, just as the first step of slight magnification opened up a new world to us, so a second step has brought new and important conceptions of great potential service.

Have we not good reason to hope from the past that like important knowledge awaits further increase in our powers of magnification? Have we not every reason to believe that this knowledge is there to-day, behind that closed door, awaiting its unlocking by him who shall devise the key? No doubt the technical difficulties are extreme, but surely the reward which awaits success should be proportionally great.

A group of papers, presented and taken as read, discussed various other aspects of the microscope, its use and applications.

THE MEASUREMENT OF GRAIN SIZE.

By Zay Jeffries, Cleveland, Ohio.

Just as the telescope has given us certain information in astronomy which we know no other way of obtaining, so the microscope has permitted us to obtain direct knowledge concerning many things unresolvable with the naked eye. Much of the knowledge gained with microscopes would not be obtainable in any other way. For example, the quantitative determination of grain size of fine grained metal is only possible because of the microscope. The purpose of this brief note is to point out a case in which chemical analysis varies but little, and success or failure depends on the grain size which can be determined only with a microscope.

In the mechanical working of tungsten it was found that some lots of metal would work well, and some only with great difficulty. Sometimes the metal would be so hard that it could not be drawn to the smaller sizes; it would either break too frequently or the die wear would be so great that it could not be tolerated. A careful study of these materials was made from both chemical and physical standpoints. The chemical analysis was found to be so nearly constant that errors of analysis would mask any differences which might actually be present. It is not maintained that slight differences in analysis did not exist, but only that the determination of the impurities which, aside from thoria, probably did not exceed 0.05%, gave no definite clue to the difficulty.

It was found that the variation in grain size was greater than the variation of any of the chemical or physical properties, and that the working properties varied with the grain size. The larger grains had more ability to stand extreme deformation than the smaller ones. On the other hand the tendency to break in the early stages of working was greater in the coarse grained material. If the grains were too small in the tungsten metal containing 0.75 per cent. ThO_2 the wires broke frequently in the smaller sizes and the die wear was excessive. In this metal the danger line is reached if the number of grains per square millimetre exceeds about 6,000. On the other hand, it is desirable that the tungsten metal have an inherent high resistance to grain growth to insure a long life in the lamps. This factor is usually satisfied if the number of grains per square millimetre exceeds 1,500. It is, therefore, desirable to control the grain size between 1,500 and 6,000 grains per square millimetre in the ingot.

In the early days of working tungsten no such control was exercised and lots of metal were encountered which were unworkable, and no one knew the reason. The inference now is that the ingots were too fine grained since it is possible to reproduce these results with fine grained metal to-day. A contributing, and sometimes the major cause of trouble was the failure to eliminate the oxide of tungsten, but even this is more readily detectable with the microscope than by chemical analysis.

Every lot of tungsten metal made at the Cleveland Wire Division of the General Electric Company is now tested for grain size; in fact, treated to give the proper grain size in many cases. The lots not falling

within the proper limits of grain size are not subjected to the working process, which costs on the order of twenty times as much as the preparation of the ingot.

The method of quantitatively determining the grain size has been described by the author in the *Transactions of the Faraday Society*.* A circle 79.8 millimetres diameter is drawn on a ground glass, and the image of the properly etched sample is brought into good focus. The grains intersected by the circumference of the circle are counted and multiplied by .5 (in the paper above mentioned this factor was given as .6, but later results show that .5 is both more accurate and simpler to use),† and this product is added to the number of grains completely included. The sum is the number of whole grains within the area represented by the circle.

It is true that the determination of grain size in other metals, such as alpha brass, has been used as a help to works control, but the application of this is not very extensive and not as necessary as with tungsten. Other differences are manifest which may be easier to determine than the grain size. Several metallographists have told the writer that they had investigated the variations in grain size and found that the physical properties did not vary greatly with considerable variations in grain size, and hence they had concluded that the test was not suitable for their purposes. It is for this very reason that the writer believes that many other special cases will arise in which a considerable change in grain size will correspond to but slight differences in certain other properties (like the working properties in tungsten), and these properties may be controlled within narrow limits by controlling grain size. In fact, metals or alloys other than tungsten have certain properties which can be controlled only by controlling grain size or other structural features, but these structures are produced by uniform processing determined by experience, and the actual quantitative determination of grain size is not necessary. With the modern demand for uniformity of product and high standards, the manufacturing tolerances will be reduced, and extended use of grain size control may be expected. Even now the defective loss in the mechanical working of metal could be reduced in many instances by properly controlling the grain size in the various stages of processing. In large plants the lessening of the defective loss a fraction of one per cent. would more than pay the cost of investigation and upkeep of these control methods.

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* Vol. XII, Part I, 1917, p. 40.

† Metallurgical & Chemical Engineering, p. 185, Feb. 15, 1918. Also Sano and Ohashi, Proc. of the Physico-Mathematical Society of Japan, 3rd Series, Vol. I, No. 7, p. 216, treat this method of grain size determination mathematically, and conclude that "Jeffries' formula . . . is quite sufficient for practical purposes."

NOTE ON MICROSCOPE MICROMETRY.

By Professor W. M. Thornton, D.Sc.

In the increasing use of the microscope by engineers for the measurement of small objects which cannot be dealt with by usual micrometric methods, the need is occasionally felt of a means of calibrating the eye-piece micrometer. For this purpose it is convenient to have a scale one centimetre long photographed on a glass slide, and divided into millimetres, half millimetres, tenths, hundredths, and possibly thousandths.

This is covered with a thin slip of mica or glass cemented on round the edges.

The object of this note is to call attention to the convenience of the combination of such a scale with a fully divided ocular micrometer as a means of calibrating rapidly and with sufficient accuracy for most purposes, any system of eye-piece and object at any extension, in microscopes not fitted with travelling micrometer stages. The idea is no doubt old, but enquiry over a wide area has shown that it is not in use by those making daily observations, and to engineers and physicists who are not in immediate touch with microscope theory and formulae it may be useful to have both a loose scale in the eye-piece and a graduated slide for calibration.

Dr. Maurice Langeron, Chief of the Laboratory at the Medical Faculty, Paris, presented the following papers on behalf of **Dr R. Bazin.**

MAKING ENLARGED-SCALE DRAWINGS AFTER BAZIN.

The device dispenses with a camera lucida, and consists of an ordinary biconvex lens A, giving a virtual, erect and enlarged image of the object OO, which is placed between the lens and its focus; Fig. 1 explains the arrangement. An image of the paper and of the point of the pencil C is formed on the plane on which the object rests, being produced by the plano-convex lens B of short focus; this image is real, reversed and reduced in size, because the paper is at great distance beyond the focus. The biconvex lens A enlarges both the small image of the pencil point and the object itself, which are in the same plane. In drawing one has merely to trace the outline of the image.

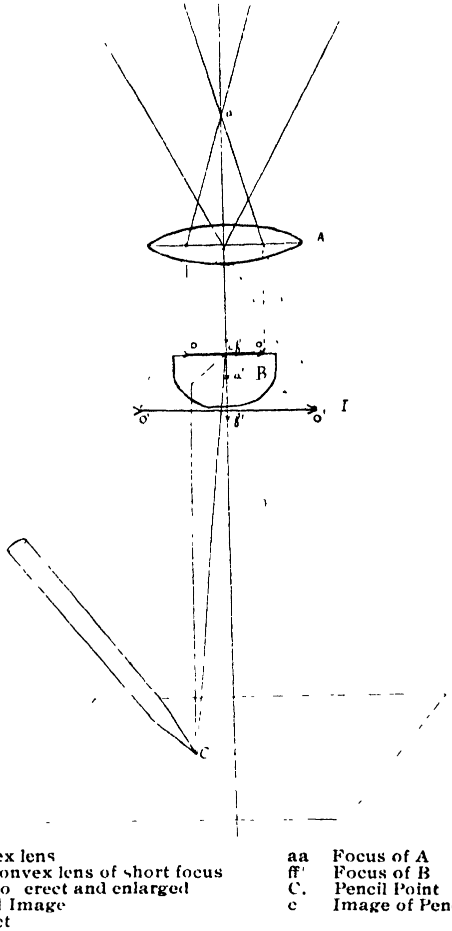
EYE-PIECE GRATICULE FOR DRAWING, MEASURING AND COUNTING.

(Bazin's Réseau Oculaire.)

When painters wish to copy a picture on a different scale, they divide the photograph of the picture, as well as the canvas on which they are going to paint, into small squares. Each little square is then filled up.

The réseau oculaire, or eye-piece graticule, consists of a plate on which lines, very fine, yet as distinct as possible, form a system of squares of 1 mm. size. This plate is placed on the diaphragm of the eye-piece.

In drawing one makes use of squared paper, and the microscopic image is reproduced in the way that the painter copies his picture. To facilitate taking measurements, one of the squares in the centre (see Fig. 2) is subdivided into four smaller squares, and one of the small squares is again subdivided in the same way, with the aid of a micrometer objective. Thus measurements can easily be made.



A Biconvex lens
B. Plano-convex lens of short focus and o.o erect and enlarged
I. Vertical Image
O O Object

aa Focus of A
ff' Focus of B
C. Pencil Point
c Image of Pencil Point

FIG. I

When particles are to be counted, the diluted blood or bacteria preparation is placed in some cell which need not be squared; the thickness of the cell must be known. It will be possible to count the number of globules approximately, provided that one can get them displayed in a single layer. The volume of the little drop adhering to the pipette being known, the area which the drop occupies can be measured with the aid of the graticule; by counting the mean number of red corpuscles per square, an approximate estimate

can further be formed of the number of elements containd in the drop. In the same way parasitic organisms and leucocytes can be counted.

The réseau also serves as a reference system of co-ordinates, and can replace the pointer of the eye-piece. (The device was described in the *Bulletin de la Société de Pathologie Exotique*, Vol. XII., p. 135, 1919.)

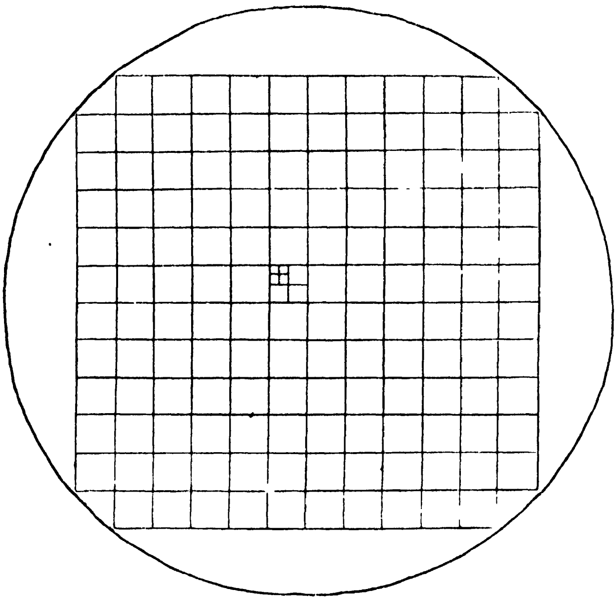


FIG. 2.

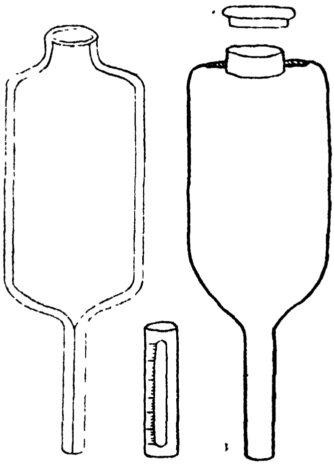
BAZIN'S CAPILLARY CHORESIMETER.

The haematocrite makes use of centrifugal force for the purpose of counting the number of blood globules. With a similar apparatus bacteria suspended in distilled water can be counted; their small size calls for a special device, however.

A glass flask, of a capacity of 20 cub. cm., is terminated by a capillary tube, 0.2 mm. bore, 4 cm. long. The extremity of the tube is closed by a rubber disc kept in position by a stirrup which can be turned about its axis (see Fig. 3). The stirrup is supported by a metal collar encircling the neck of the flask. The upper aperture of the flask is hermetically closed by a metal stopper, which is provided with a rubber packing and screwed into the collar. To prevent any slipping of the stirrup during the centrifugation, the capillary tube, together with the stirrup, is enclosed in a sleeve of copper or brass. The capillary tube is filled with distilled water, the rubber disc is applied to its lower end, and the stirrup turned down. The bacteria suspension is poured into the flask, the stopper screwed in, and the sleeve mounted. The apparatus is then placed in the container of the centrifugal machine, which is turned for ten minutes at 7,000 revolutions. The bacteria collect in the capillary

tube, and are watched through the two symmetrical slots in the sleeve. Measurements are taken with the aid of a vernier and a lens. The appâratus is calibrated with the aid of bacteria suspensions of known numbers.

The capillary tube should neither be too fine nor too coarse; in the former case the capillary might become clogged, in the latter the precision of the measurement would be impaired. The dilution



Flask and Capillary Tube Graduated Brass Sleeve with Slot Stirrup and Stopper

FIG. 3.

of the suspension must also be suitable, as a concentrated preparation would entirely fill the capillary. The distilled water used should carefully be filtered, since a small particle, *e.g.*, of cotton, would stop the tube. In order to facilitate comparative determinations, a standard tube containing a suspension of known titre, of particles of known dimensions and density, should be used; porphyrised kaolin may serve for this purpose, after levigation and filtration.

THE GRAYSON RULINGS

By Dr. A. E. H. Tutton, F.R.S.

It must have been with the deepest regret that workers with the microscope heard of the premature demise of Prof. H. J. Grayson, of Melbourne, the remarkably gifted maker of the well-known "Grayson Rulings." Those who have used the rulings have been struck with both their accuracy as regards spacing, and the extraordinary sharpness of each individual line, especially in the case of those on speculum metal. The truly wonderful guiding of the diamond point by the late Prof. Grayson's own unique master hand, no less than the perfect construction of his ruling machine, which enabled such accurate spacing to be obtained, have never ceased to impress those who have worked with these rulings. Their merit begins at the point where the other rulings so well known to us, such as those of Rowland and of Michelson, leave the field, namely, above 20,000 to the inch. His extreme rulings of 120,000 to the inch, are a direct challenge to the microscope, for they represent its highest resolving power. While these wonderful rulings, and those only a degree less impressive of 100,000 and 80,000 to the inch, are of great use to us in studying high resolution, with natural microscopic objects presenting detail of great minuteness, and also in actual calibration and measurement of the detail of objects of such extreme minuteness, it is probably with the more moderately spaced rulings of 60,000 and 40,000 to the inch that the most important work is to be done.

The writer has already called attention, in his memoir* to the Royal Society on the Interference Comparator for Standards of Length, to the fact that the Grayson rulings of 40,000 to the inch spacing are capable of becoming of great importance in metrology, as fiducial marks, the middle one of five such rulings forming an excellent signal-mark. For, as was pointed out in the memoir, the 40,000th of an inch is the wave-length of red light, very close indeed to the exact wave-lengths of the red hydrogen ($\frac{1}{38710}$ inch) or the red cadmium ($\frac{1}{39459}$ inch) line. Thus, the space between any two successive lines of the 40,000 to the inch rulings corresponds practically exactly to the passage of two interference bands (two complete interference-band spacings) in red hydrogen or cadmium light. That this is true of the late Prof. Grayson's rulings labelled by him as 40,000 to the inch, has been proved by the writer by direct measurement against the interference bands, on the Comparator at the Standards Department. These more moderately finely spaced rulings are admirably resolved by the 1/15th inch dry objective supplied for the purpose by Mr. Conrad Beck. The lines, indeed, as seen through the fine-movement micro-

* Phil. Trans., A., 1910, *210*, 30.

scope, are as clear as the interference bands in the interferometer of the Comparator, and the writer expressed hopes in his memoir to be able to carry out with their aid the determination, by this original method, of the exact number of red cadmium wave-lengths in the British Yard. Such a determination would, indeed, be quite simple and straightforward, with the proviso that an adequate supply of the rulings required for the stepping off process could be obtained.

The writer also hopes to use them as fiducial marks in connection with interferometric fine-measurement in general, and a General Interferometer, involving the same type of travelling fine-movement microscope as those (the pair) on the Comparator, is being constructed for him for the purpose at this moment.

The breaking out of the great war, and now the unhappy death of Prof. Grayson, have delayed the possibility of further work on the subject, and as doubtless other workers in high power microscopy are also at present unable to carry out their own particular researches for which the higher rulings are essential, the writer considers it desirable that the position shall be discussed at this Symposium of Microscopists.

The writer's suggestion is that the Symposium should address to the Governing Body or Council of the University of Melbourne a letter of condolence, expressing firstly the unanimous opinion of the great body of Microscopists and Scientific workers here assembled of the very great loss which the University has suffered by the demise of Prof. Grayson; and, secondly, the hope that the University will do all that is possible to ensure that Prof. Grayson's ruling machine shall still be available for the production of the "Grayson Rulings." It may be that Prof. Grayson had trained one or more members of his staff in his method, and if so it should not be difficult to arrange for the most highly desirable continued production of the rulings.

The writer took the opportunity of mentioning the matter to General Sir John Monash, the gallant Commander of the Australian Forces, and a member of the Governing Body and Council of Melbourne University, on his recent visits to London and Oxford on the conclusion of the War, and he kindly undertook to go into the question on his return to Melbourne. Possibly General Monash's relative, Dr. Rosenhain, whom we know to be interested so keenly in the subject from the microscopical point of view, and who has intimate connections with Melbourne and its University, will also be inclined to assist in carrying the subject further.

The continued production of the Grayson Rulings, especially those of the 40,000 to the inch spacing, is so important a matter that the writer has felt sure that the Symposium would wish him to bring it forward.

THE TESTING OF MICROSCOPE OBJECTIVES AND MICROSCOPES BY INTERFEROMETRY.

By F. Twyman.

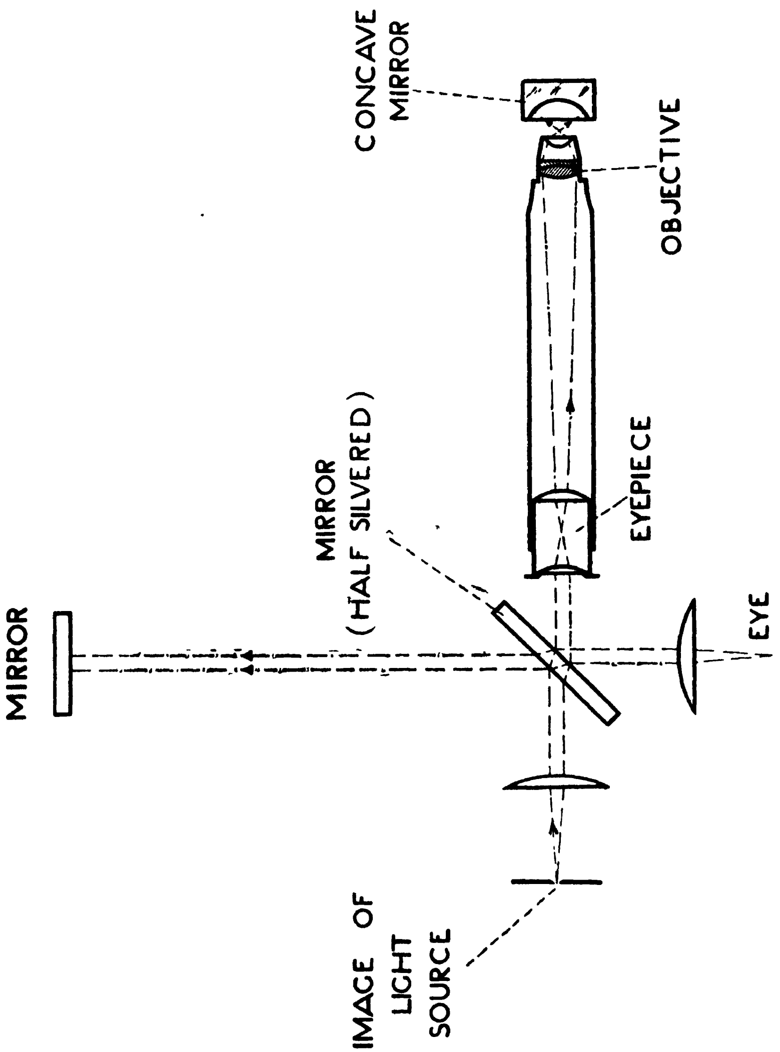
My firm has no commercial interest in microscopes, and so far I have not succeeded in interesting any microscope makers in the methods of test I shall describe. We have, therefore, not done much more on the subject than to test a few microscope objectives, and these, although by makers of repute, not of high power. They show aberrations of wave surface not exceeding about $\frac{3}{4}$ wave-length for monochromatic light (wave-length 5461). It will be remembered that if aberrations do not exceed $\frac{1}{4}$ wave-length, the resolving power of an optical system is practically perfect. This was found by Rayleigh to be the case in certain cases calculated by him, and general experience shows it to be a sound rule.

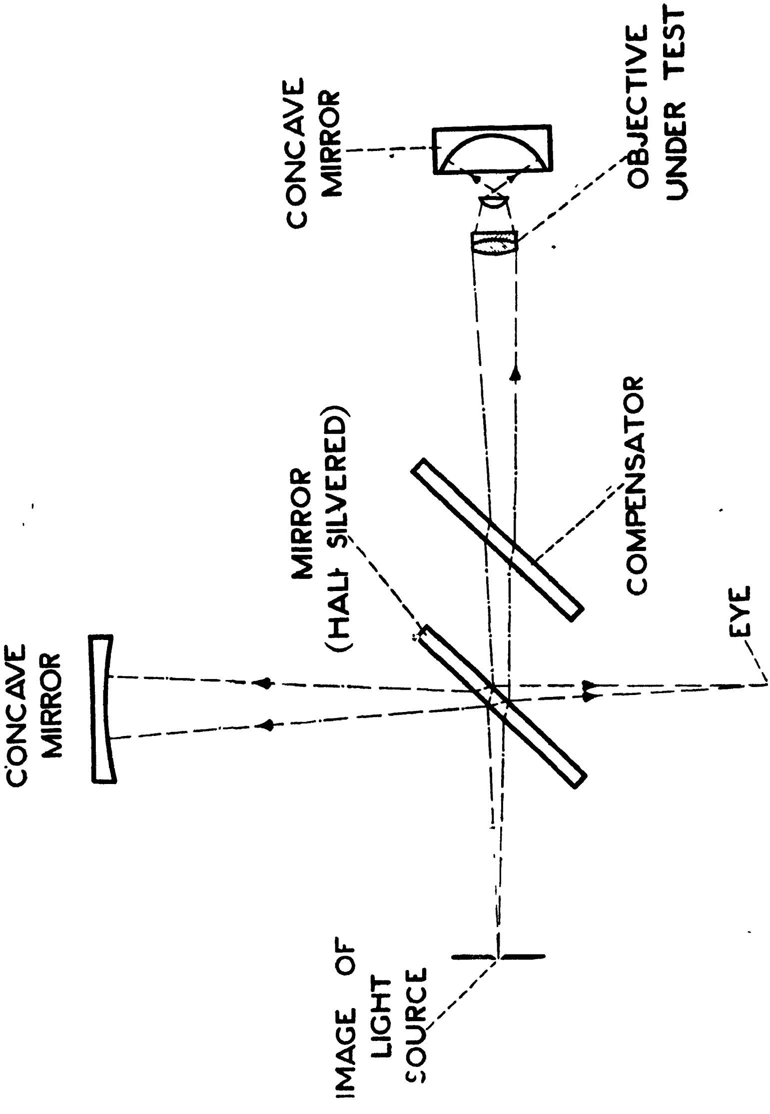
The interferometer used for microscope lenses was a side issue in the development of other forms.*

An image of a monochromatic light source is thrown on a diaphragm which has a small hole. The light passes to a half-silvered mirror (Figure 1). A portion of the light is reflected from there to a concave mirror so situated that the diaphragm is approximately at its centre. From the concave mirror the rays are reflected, and a portion of the light passes through the half-silvered mirror, and is focussed on the eye of the observer. The light which, on meeting the half-silvered mirror passes through it, proceeds through a compensating plate as in the Michelson Interferometer; then through the objective under test. The rays pass on through the image, and are reflected back on their own path from a concave mirror. Eventually the two beams of light combine at the surface of the half-silvered mirror, and pass on together to the eye. In these circumstances interference effects are observed which appear to the observer as if located on the back lens of the objective under test, and which represent a contour map to a scale of half wave-lengths of the aberrations of wave surface produced by the objective under test.

If desired, an entire optical instrument, such as a microscope, can be tested, in which case the arrangement is as shown in Figure 2.

* Described by the present writer in the *Phil. Mag.*, Vol. XXXV., January, 1918, "Interferometers for the experimental study of optical systems from the point of view of the wave theory."


CONCAVE MIRROR
OBJECTIVE
EYEPIECE
MIRROR (HALF SILVERED)
MIRROR
EYE
IMAGE OF LIGHT SOURCE


CONCAVE MIRROR
OBJECTIVE UNDER TEST
MIRROR (HALF SILVERED)
COMPENSATOR
EYE
CONCAVE MIRROR
IMAGE OF LIGHT SOURCE

AN ACCURATE METHOD OF OBJECTIVE AND SUBSTAGE CONDENSER TESTING.

By H. Hartridge, M.A., M.D.,

Fellow of King's College, Cambridgf.

Preliminary Communication.

The methods of objective testing at present in use do not give quantitative data, and depend to a great degree on the keenness of vision, skill and memory of the observer.

A method which does not suffer from these defects consists in measuring with a suitable micrometer the position the image pattern when different parts of the objective aperture are used. If the lens is perfect and in correct focus no movement of the image pattern occurs. If there is movement, however, and if the micrometer reading be plotted against the N.A. of the part of the objective aperture in use, then the graph thus obtained shows the aberrations that are present and their amount.

A suitable method of isolating objective apertures of given N.A. was obtained by moving by means of a graduated micrometer screw a slit-shaped aperture placed below an oil immersion condenser. The method of calibrating the micrometer in terms of N.A. has been previously described.(1)

The best eye-piece magnification was found to be about 100 diameters; this was obtained by a 2-3 in. objective and a ×10 eye-piece.

The glass plate micrometer proved most suitable for measuring the displacements of the image patterns.

The method of illumination has already been described.(2)

The typical graphs obtained for certain aberrations may now be briefly described.

Centre of Field.

Perfect lens (a) correct focus:—a straight vertical line; (b) incorrect focus:—a straight inclined line; (c) incorrect tube-length:—S-shaped line.

Imperfect lens (a) spherical aberration:—a sinuous line (not of regular S-shape), and never a straight line; (b) central astigmatism:—a different curve in one azimuth to that given by another.

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(1) Hartridge, Journ. Roy. Micro. Soc., 1918, p. 337.
(2) Hartridge, Journ. Quekett Micro. Soc., Nov. 1919.

Periphery of Field.

. A straight vertical line indicates perfect lens in correct focus.

(b) An inclined straight line shows perfect lens in incorrect focus. If the inclination is different to that found at the centre, the difference shows the degree of curvature of field.

(c) A bent line denotes presence of aberrations:—disobedience of sine conditions, etc.

Experience shows that "performance curves" for the centre of the field show almost at a glance the aberrations present, and their degree. Interpretation of curves for the periphery of the field is more difficult.

Colour filters only have so far been used for obtaining approximately monochromatic light, a prismatic spectral illuminator would be a valuable addition.

It will be observed that this method of objective testing has been developed from the method of adjusting tube length described in a previous paper.(3)

(3) Hartridge, Journ. Roy. Micro. Soc., 1919, p. 119.

REMARKS BY SIR HERBERT JACKSON, K.B.E., F.R.S.*

By the courtesy of the Chairman I was able to see in advance a great number of the interesting papers which have been prepared for this meeting to-day, and when I looked at them I discovered that practically everything that I intended to say was included in those papers. I have decided, therefore, that it would be better for me to be brief, and deal very generally with perhaps only two or three points.

I take it that one of the chief reasons for this Symposium is to consider methods for promoting the study of the microscope and methods for extending its use in science, in industries, and in education. I should like to mention first the position which we are in at the present day with regard to one of the most vital parts of the microscope, namely, the optical glass. I should like this meeting to know that through the enterprise of British manufacturers we have produced and we can produce optical glass in this country of a quality equal at least to the very best that was ever obtained from abroad. I should like also to say that I have had it from the manufacturers themselves that they are perfectly prepared to do their very best—and they have already shown that they can do it —to produce any glass which may be called for. There is a great deal yet to be done, not on their part so much, perhaps, as on the part of those whose duty it is to make investigations with the object of obtaining new glasses with optical constants differing from those which have been made hitherto, so that combinations can be made of even higher quality than those which we are familiar with in the best lenses that exist. I think also that it should be well known that, through the efforts of the Department of Scientific and Industrial Research and in other ways, mathematical investigation on methods of designing lenses are in progress, and I think we may look definitely from these investigations for results which will make a heavy demand again upon the skill and the enterprise of the manufacturers of optical instruments.

I will not speak, as I had intended to do, on some comparisons between the results of the work of British and foreign manufacturers, except to say that it is certainly true that we have produced optical trains in this country comparing favourably with any produced anywhere else, but we do not always produce them with that constant accuracy. I think it is fair to say that while, in the early history of the microscope we took the initiative, in later years there has been a tendency to follow rather than lead. At least, that is true of some of the chief developments of the instrumental part of the microscope. Now, what we have to do is no longer to copy, but to aim at improvements by independent research and invention. There exists at the present time, fostered by the Department which I have just mentioned, an all-round spirit of research and enterprise. Without elaborating the point, one can now express the hope that a bright promise of future development will not fail of fulfilment through lack of means on the one hand to attract the brains and skill which are abundant in this country, and on the other hand to

* See above, p. 43.

make possible the large amount of experimental work which is needed and which of necessity cannot be made to pay except indirectly, and in the course of time. Unless we can get experiments of that kind made by the people in the factories, the hoped-for advances from the instrumental side will not be fulfilled, at least to the extent which some of us think and believe to be possible.

I turn for the moment to the point of view of education. The growing use of scientific instruments in industry definitely calls for some systematic education in the theory of them and in their practice. There has recently been created a School of Technical Optics under the Directorship of my friend Professor Cheshire. We may therefore look confidently to having opportunities afforded for a thorough and systematic education, now so much needed, in the subject of the microscope and its use. That need existed over 25 years ago, but I do not know that any marked efforts have been made to give the systematic education required. Take the difference between the subject of spectroscopy and microscopy. In spectroscopy the work of educating the student is carried out in a systematic way. There is lecture work and laboratory work, and I think the student of spectroscopy knows his instrument and his subject as well as it is possible to do in the time he is required to spend on it. It is difficult to believe that the student of microscopy ever had a chance of knowing his subject so systematically and thoroughly. Therefore I plead very strongly for the greatest possible support for Professor Cheshire, so that he may bring this question of education in the microscope to a really practical and successful issue. Of the many possible forms of propaganda, none is likely to have a better or more lasting influence in the direction of arousing interest in the subject and extending the use of the instrument. How many of us have seen people who begin with the microscope and abandon it very soon after taking to it, and in nearly all cases it has been due to this, that they have had nobody to show them how to use the instrument or to make them understand what the microscope is, what it is in theory and in practice, and they have often not been able to interpret what they see.

We have listened to an Address by Mr. Barnard which is very interesting to me, because I have had the opportunity of seeing his work, and I think he is to be congratulated on the scientific work he has done in extending the use of the microscope. But it is more than that. Mr. Barnard has that spirit of research and that spirit also of realising that there is to be interpreted in the microscope a great deal that has escaped observation, although it may have been seen dozens and even thousands of times. What I want to see is, in addition to the necessary lectures on the theory, the formation of classes in the use of the microscope where objects are studied at low powers and low numerical apertures and at high powers and high numerical apertures, by transmitted light, on a black ground, and by opaque illumination; and each appearance critically examined and described.

There is a definite lesson as to how each type of image is to be interpreted. May I take one or two instances. If a well-known diatom, *pleurosigma angulatum*, is examined with an illuminating cone of not more than .3 to .4 N A , and with a lens like a 1 inch,

by ordinary transmitted light, what is seen is a brown or yellow-brown object. I am not going into the theory or the details, because it would take too long, and I am speaking to experts who, I am quite certain, know perhaps better than I, what is the explanation of the brown colour. But how many people who have looked at it simply as an object have asked "Why is it brown?" If you take that same object with a black ground illumination and a low angle objective, using an illuminating cone of .4 numerical aperture, all you see is the outline of the specimen. Yet what a wealth of information is to be gained from an investigation of the inside of that outline; Mr. Barnard has well indicated that when he was speaking of work in connection with the yeast cells. If you raise that cone to .65 with a black ground illumination, with the same objective, the object then is a beautiful blue or violet colour. Raise it still higher and it gets nearer to a greenish colour, and if you put on a little higher angle lens with an immersion condenser, the object looks very nearly white; raise the angle still a little higher and the image is white. That is an illustration of why every change should be explained and interpreted. Take another illustration: *tous-les-mois* starch grains mounted in water. With a black ground and an objective of a numerical aperture of .26, it is really a pretty object. The grains are nearly all pearly white, and the concentric rings can be seen quite well. If you keep the same objective, but raise the numerical aperture of the condenser, all the beautiful light goes, and nothing more than a mere outline can be seen; it looks like a little ring of light with nothing inside. Raise the aperture of the objective and use an immersion condenser, and you begin to see a little more showing up inside, and that is the first indication of the existence of a structure there. I should like the same thing to be taken with an opaque illuminator and examined. Opaque illumination, except in the examination of metals, has not had the attention paid to it that it should have because we have not laid sufficient stress on the necessity of looking at the object from all points of view, so as to decide by a careful comparison of the appearances in every possible form of illumination, the correct and proper interpretation. The student might be encouraged to go through a systematic course of theoretical and practical microscopy, applying what he learns in lectures to the study of objects of comparatively well-known structure by their examination with optical systems of increasing power and with various forms of illumination until he has gained a real knowledge of what can be revealed by the microscope and of what are its limitations. With this experience he would be in a position to proceed to research work equipped with sound theory and the fundamental practical knowledge necessary for the interpretation of what he sees and the avoidance of hasty judgment through incomplete observations.

If we could look forward to educational work somewhat on these lines in the future, people who wanted to study microscopy would find there was a great deal of valuable work to be done in extending the use of the instrument. The brilliant work which Mr. Barnard is doing in connection with ultra-violet light and increased resolving power cannot but help us very much in interpreting many things which we have seen but have not understood.

The following papers are extended descriptions of exhibits shown before the meeting.

NOTE ON LIGHT FILTERS FOR THE MICROSCOPE AND PHOTOMICROGRAPHY.

By LT.-COL. GIFFORD.

As far back as 1894 it was found that a solution of malachite green in glycerine absorbed all the visual spectrum except a broad band in the region of the F line of the solar spectrum, and a narrow red band near B (J.R.M.S., 1894, pp. 164-7), and that such a solution placed in a glass trough was eminently effectual as a light filter for microscopic use, especially when the red band was removed by inserting a piece of signal green glass into the fluid.

The year following, a screen similarly constructed, but with a solution of methyl violet for use in photomicrography, was described (J.R.M.S., 1895, pp. 145-7). In recent years it has been found that peacock-green glass possessed the same properties as signal green to a greater extent, and the use of the latter has therefore been dropped.

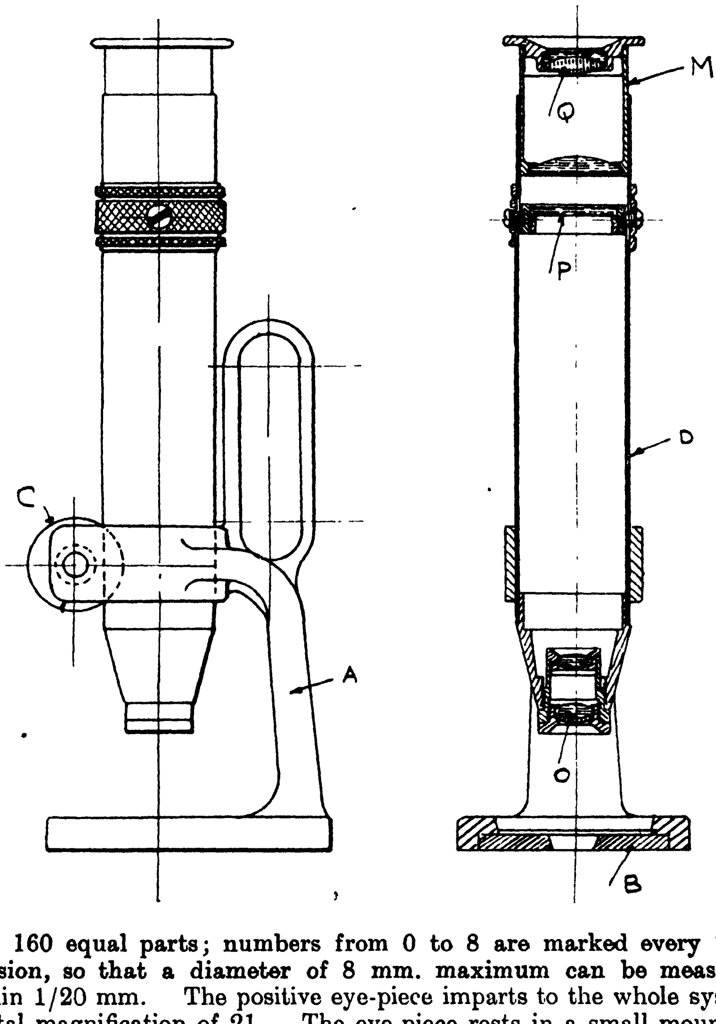
Instead of the glass trough with the signal green placed in it, the form these light filters have recently taken is as follows:—Discs of peacock-green glass about 0.06 in. thick and of diameter to fit into the substage condenser are cut out. On these discs are built up cells, using gold size and soft metal rings, or the former alone, just like those made for mounting microscopic objects in fluids. If a metal ring is used, then a coat of size must be given to the top of it and be allowed to dry. Then a final coat must be placed on that and allowed to get tacky. Then place rather more than sufficient dye solution in the cell near the edge. The glycerine will cause it to stand up beyond the top of the cell. Take a clean glass cover, make contact with the tacky gold size at a point nearest the drop of dye. The point of contact will act as a hinge. Now allow and assist the cover to fall until in contact with the gold size all round the ring. While the cover is falling and this contact is extending, the dye solution will flow forward and out in a wave. When contact is made with the top of the cell all round, take any blunt instrument and press the cover down in the middle until still more dye flows out. While this is being done adjust the cover on the ring if necessary, by the direction of the pressure. Quite a considerable pressure may be used, cover glasses are very flexible. When enough dye has passed out to leave the cover slightly concave, and you are assured that the adjustment is correct, suddenly remove the pressure. Pneumatic action will at once take place, owing to the resilience of the indented cover, and the edge of the latter will adhere so tightly to the gold-sized ring that it is possible to wash under the tap with a full stream of water at once. If made as described, the cell will not give out. Light filters made in this way are shown; one of them has been made and used for more than 20 years.

MICROSCOPE FOR MEASURING BRINELL IMPRESSIONS.

(Constructed by the Société d'Optique et de Mécanique de Haute Précision, Paris.)

The apparatus consists of two principal parts: the microscope properly speaking, and the limb or support.

The microscope itself comprises a mount D, carrying below an objective O, and above a micrometer P and an eye-piece Q. The objective is aplanatic and achromatic, and yields a linear magnification of 2.5. The micrometer has a length of 20 mm., which is divided



into 160 equal parts; numbers from 0 to 8 are marked every 20th division, so that a diameter of 8 mm. maximum can be measured within 1/20 mm. The positive eye-piece imparts to the whole system a total magnification of 21. The eye-piece rests in a small mounting M, which can glide in the tube D for adjusting the eye-piece with respect to the micrometer.

The support A consists of the foot, a mount, a split collar provided with a clamping screw and a handle. The microscope fits with gentle friction into the collar, so as to be definitely adjustable with respect to the impression to be measured; it is then fixed in that position by means of a screw C. In the base of the support is encased a disc of fibre B, which is provided with a central aperture through which the impression to be measured can be examined This fibre washer, as shown in the annexed diagram and in the model, may be replaced by a washer of suitable shape, so as to be adaptable to the piece to be examined by the microscope. The microscope weighs 0.390 kg.; the mahogany case weighs 0.650 kg.

THE DAVON PATENT MICRO-TELESCOPE AND SUPER MICROSCOPE.

Exhibited by F. DAVIDSON.

This apparatus combines in standardised and instantly interchangeable form the functions of the microscope, telescope, camera and projecting lantern for laboratory, educational and industrial purposes.

The principle employed is the utilisation of an " air " image of a more or less distant object projected to the plane of the microscope stage by means of lens attachments which are inserted into the " Abbe " rim of the microscope stand, and then using the microscope itself as an eye-piece.

Three different attachments are brought into requisition, viz. the long focus attachment, the short focus ditto, and a micro object glass forms the third. The first transforms the microscope into a telescope with a range of vision of from six feet to infinity, and magnifications of 20 to 50 diameters. The second is used for objects which, by reason of their size or shape, cannot be examined on the stage of the microscope, such as minerals, metal fractures, etc., the visual range being from three feet to one foot from the stage of the microscope and magnification from 30 to 90 diameters. The third in combination with the microscope itself forms the super microscope. Magnifications of from 75 to 150 diameters with working distances of from four to two inches or of 1,500 diameters with working distance of $\frac{1}{4}$ in. are characteristic features.

Either attachment may be used for photography. With the first, photographs have been taken at distances of 6 feet and 70 miles, with the same combination; with the second, insects at from 18 ins. to 24 ins.; and with the third attachment, photomicrography of a wide variety of subjects at various magnifications from 1 to 3,000 diameters with excellent results.

The outstanding feature of all views and all photographs is the very great " depth of focus." This is so good that everything is shown in apparent stereoscopic relief.

The principle of photography with either attachment is the same, and consists of substituting a camera for the body tube of the microscope and virtually using a microscope objective as the eye-piece. No long extension camera is therefore necessary, exposures are shortened and vibration minimised in high power photomicrography. Photographs of Himalayan Peaks 60 miles away, and blood corpuscles at a magnification of 3,250 diameters have been taken in a $\frac{1}{4}$ plate without more than the ordinary extension.

The illuminant is arranged in an optical lantern with a 4 in. condenser and a supplemental condenser in a mount which fits the " Abbe " rim of the microscope. For projecting light on to a more or less distant object the 4 in. condenser is used alone. For photomicrography the supplemental condenser only is used, while with the two in combination effective micro-projection may be done without any accessories.

It is impossible in a briefly outlined description of the apparatus to indicate the wide variety of uses to which the apparatus lends itself, and it is no exaggeration to say that a new and wider field of observation and utility is opened up in many directions.

DISCUSSION AT SHEFFIELD.

Tuesday, February 24th, 1920.

At a meeting of the Sheffield Association of Metallurgists and Metallurgical Chemists held at the Royal Victoria Hotel, Sheffield, on Tuesday, February 24th, 1920, further discussion took place on those papers presented at the Symposium at London, on January 14th, which dealt with the use of the microscope in Metallurgy and Metallography.

The meeting was held in co-operation with the Faraday Society and it was attended by members of other local bodies and by the members of the local sections of the Institute of Metals and the Society of Chemical Industry.

Mr. J. H. S. Dickenson, President of the Sheffield Association of Metallurgists and Metallurgical Chemists, was in the chair and he presided over a large audience.

The CHAIRMAN, having explained the objects of the meeting, called upon **Dr. F. C. Thompson, Mr. T. G. Elliot, Mr. J. H. G. Monypenny** and **Mr. F. Atkinson** to introduce briefly the papers they had contributed to the Symposium in London. Other papers were distributed in proof form.

DR. THOMPSON'S paper was entitled "The High Power Photomicrography of Metals."

SIR ROBERT HADFIELD and MR. T. G. ELLIOT'S paper was on "Photomicrographs of Steel and Iron Sections at High Magnification."

MR. J. H. G. MONYPENNY'S paper was entitled "Some Notes on the Metallurgical Photomicroscope."

The paper by MR. LESLIE AITCHISON and MR. F. ATKINSON was entitled "Metallurgical Microscopes and their Development."

Discussion.

Dr. W. H. Hatfield did not think that there was any point on which he joined serious issue with the authors of the papers read that evening. Mr. Monypenny said that many people used the microscope and did not properly understand it. That was so. But looking at it from another point of view, there were people who regarded the microscope as a tool and looked to the manufacturers and the optician to further extend its usefulness. That was his position, and, generally speaking, the position most metallurgical investigators would take up. From that point of view one could tell the people who were making a speciality of the microscope what the metallurgist wanted. We might first of all tell them what we could do. From his own metallurgical experience he could obtain delightful microphotographs under ordinary conditions, and with ten magnifications get excellent empirical microphotographs. This was also the case with 50, 100, and up to 1,000 magnifications—excellent, almost perfect definition could be obtained. Beyond 1,000 diameters, however, we could not do so, and that was an essential thing to put before the people who were out to assist us in the use of the microscope.

There were a whole series of problems awaiting adequate solution, including the recrystallisation of cold-worked material, and solutions could only come when we have better facilities for definite and accurate information as to the internal architecture of the material at magnifications well above a thousand. We had produced very pretty photomicrographs up to three thousand diameters—Sir Robert Hadfield has produced excellent ones up to eight thousand—but these magnifications did not give us much more information than we could obtain by a clear definite picture at a thousand. If the Symposium had brought those facts before the notice of manufacturers of the microscope, it would have served a great purpose to metallurgists.

Dr. F. Rogers thought that the theory of lens design had been evolved much further than the theoretical side of metallurgy itself, heretical as that might seem. In reference to the high magnification work done by Sir Robert Hadfield and Mr. Elliot, he emphasised that whilst magnifications of 8 to 10 thousand were interesting as pictures, they did not contain any more detail; they were, in fact, of no greater value than enlargements. Nevertheless, he welcomed this high magnification as a progressive step, even though the result as regards detail was a negative one.

He put in a plea to metallurgists that they should make their photomicrographs bigger; if they were, an advantage would be gained. Such enlargements were better understood by the non-expert, even if perhaps as a record they were not so good. In regard to fine structures in the alloy steels—especially, for instance, in the study of temper brittleness—he would welcome anything which would give further resolution of detail. This information, he felt, was hidden away from them just at the limit of what the microscope could do. He thought the microscope would ultimately contribute to the solution of that problem.

Mr. J. N. Greenwood referred to the difficulty of discussing the many points at issue. First of all there was the perfecting of the design of the optical system of the microscope itself. That was definitely a question to be tackled by the opticians. On the other hand there was the question of the use of the microscope, and in that connection there were very great improvements necessary in a good many cases. As regards the question of vibration, one speaker suggested that the people who supply the microscopes should supply some means of getting over this trouble. But the trouble could only be rectified by each user of the microscope himself, because at the various laboratories where the microscope was found the component vibrations were different. Sometimes it was the vertical which preponderated and sometimes the horizontal, and the question of the situation and the type of machinery close by had to be gone into before the vibration should be overcome.

As regards magnification, a good many metallurgists were expecting more from the microscope than was likely to be forthcoming in the near future. As far as he could see, unless there were some absolutely new development in the way of objectives we were not likely to get anything approaching the increase of magnification and resolving power which some metallurgists desired. Magnifications of 1,500 were now quite possible, and every one obtained them more or less easily. But to get at the bottom of such problems as brittleness and cold working we should have to get far beyond what we had been doing and approach molecular dimensions; even at ten thousand we were still a very long way from seeing molecules. It seemed to him that something like 100,000 would be nearer the mark, and he could not see how from the present system and using reflected light that we were likely to get anything of that order. If the opticians gave us 10,000, then they would have reached their limits with the present methods. He thought there was more prospect of getting information by examining other physical properties apart from or in conjunction with the microscope. He concluded by saying that during the past five weeks he had given more time and study to the microscope than he had during the last five years, so that in fixing attention on points like this, such discussions are invaluable, because few people had time to gather information of this kind.

Note added March 6th.—It has been suggested that I am pessimistic with regard to possibilities of higher magnification. I do not wish to convey the idea that I do not look for any improvement in magnification, but rather than in the two problems mentioned the probable improvements in the microscope will scarcely go far enough. On the other hand, there is an enormous field of utility for magnifications (with correspondingly high resolving power) of the order of 5,000, in defining the structures of special steels.

Mr. G. R. Bolsover said the papers resolved themselves into three types. A certain section dealt with the historical side, another with the utility of the microscope, and the third with the microscope as an instrument. The historical side was dealt with mainly by Sir Robert Hadfield in two papers. He suggested that in

dealing with the work of Sorby that account could with advantage be extended to include not only the work of Sorby, but his life's well. In the case of a man who had done so much for science and incidentally for civilisation as a whole, we should have a permanent record of this man's birth, training, and career in detail up to his death, apart from the question of his work.

As regards the microscope as an instrument, he agreed that it was the optician's affair. There were many comments in the papers on the different forms of microscopes. His experience had been that there were many microscopes on the market capable of giving excellent results when properly used, but they were not made to meet the particular fads of individual workers. Results were dependent more on the individual than upon the particular type used. There was in use in his laboratory four different microscopes—one Austrian, one French, one modern, and one ancient British. It was possible to get good results from all of these. The two oldest were the Austrian and the old British. The latter was perfect in almost every respect, whilst the stage of the Austrian could be moved through quite a considerable angle in the direction in which it should be perfectly rigid. He did not think they need fear much from the superiority of the Austrian make of microscope.

With regard to stages, he uttered a word of warning—do not get a levelling stage. It was a distinct advantage to have an up-and-down movement of the stage in order to avoid altering the light sources for sections of varying thickness. On the question of light there were a number of elaborate schemes for lighting for visual work, but they got excellent results with the ordinary electric bulb with the interposition of a ground glass screen. One could get a light sufficient to show all detail, and it did not tire one's eyes. As to the source of light for photographic work, he was rather interested in some of the papers in which it was suggested that the arc was too uncertain a source and suffered from flickering. They had tried both the arc and the "Pointolite," but preferred the arc, and got excellent results from it.

Mr. Atkinson pointed out that the focussing arrangement for long distance work was one that required a great deal of attention. At times a considerable extension of bellows is required to take a photograph, and unless a really good apparatus for focussing was available, it was very difficult to get a fine adjustment.

With regard to higher magnification, one direction in which he anticipated this would be an advantage was in the disproving of certain theories at present in vogue with regard to crystallisation, but there was still a tremendous field to be explored with the facilities which were now available. Another difficulty with regard to higher magnifications was the question of polishing and etching. With the present method of polishing it was practically impossible to get a plain surface to examine, and when one came to etch the difficulties were increased. The difficulties were really enormous, and until they were removed there would be great difficulty in examining steels, let alone photographing them at high magnification.

The Chairman: Dr. Thompson refers to the Reichert microscope, and says very good results can be obtained when the disc illuminator is used instead of the pair of prisms ordinarily fitted. Does he know whether such a microscope has been made by Reichert?

Dr. F. C. Thompson: Benedicks has adapted one himself for that purpose.

The Chairman: Another point is with regard to vibration, and regarding this I would point out that Dr. Rogers would not use a four-metres extension if his apparatus was established near a steam hammer. Usually in a works it is necessary to use a short extension for this reason.

Dr. F. Rogers: There is a good deal in that. I am glad that the discussion is touching on the question of vibration. It has been suggested to me that the whole apparatus should be afloat on water or oil. It seems to me a rather good idea, but I don't suggest that you should have to swim to it. I have not worked out the detail, but I think the problem will be ultimately solved in that way, perhaps combined with springs or india-rubber moorings.

Dr. W. H. Hatfield: Arising out of this discussion there is one thing I should like to say with regard to my experience. I have done a great deal of photomicrography, and for one period of something like six or seven years I used a Watson microscope. Now, that microscope cost about 50 to 55 guineas, whereas the Zeiss cost about 100 guineas. I produced well-nigh perfect pictures at 1,000 and slightly over. In fact, the work was equal to that given by the Zeiss, and I shall be glad to show anyone the slides. I mention this because so much has been said about the German manufactured article being better than the British, and I think it is only fair that we should put that on record.

Mr. L. Dufty drew attention to the different magnifications given in the various papers, and suggested that it would be a great improvement if standard magnifications were adopted. Another thing that should be stated in the papers was what objectives and eye-pieces were used. It would be a great advantage if these were given when stating the magnifications.

The Chairman: The matter of standard magnifications is mentioned in Sir Robert Hadfield's Introductory Address. The American Society for Testing Materials has issued a list of standard magnifications which, as far as my recollection goes, runs in fifties. It is open to every investigator to work to simple, round figure, magnifications.

Mr. L. Dufty: Yes, but you will see investigators often work in anything except round figures.

The Chairman: I am sometimes ashamed of some which I see hanging in my laboratory which are marked " ×117.5," but these were taken 18 years ago, and we have now for many years worked to a few fixed round-figure magnifications.

Dr. T. Baker: Those of us who have had the opportunity of examining the work of old masters in the art of photomicrography I think will agree that they, with imperfect apparatus, turned out much more satisfactory work than many of us to-day do with a much more perfect equipment. A great deal depends on the operator, and a closer study of the construction of the microscope would assist him in avoiding the pitfalls into which a good many metallurgical microscopists are apt to fall. There is a great tendency to make the metallurgical microscope too complex; amongst the fittings to be avoided are levelling stages and centering nose-pieces; a centering stage is much better than the latter, since it can be much more substantially constructed.

As regards objectives, apochromats are without doubt a valuable asset to the skilled worker, but how many can distinguish between the image formed by a good achromatic and that given by an apochromatic objective, without the assistance of the inscription on the mount; then, again, by far the greater part of the work of a laboratory does not call for the use of apochromats.

As regards magnification, it is generally stated in the standard works on the subject that little if anything is gained by using magnifications greater than 1,000 times the numerical aperture of the objective, so that until the resolving powers of objectives are increased there seems to be little advantage in pushing magnifications much beyond 1,500 diameters.

As an illuminant the speaker prefers the direct current arc to the "Pointolite" lamp, in spite of the fact that the latter has several points in its favour, such as steadiness and constancy of brilliancy. The prism form of vertical illuminator appears to have fallen into bad repute; the speaker, however, prefers it to the cover-glass type, in spite of the fact that it reduces the numerical aperture of the object by one-half in one direction, a weakness which is not such a serious matter as many try to make out.

Mr. H. Wrighton said he had considerably reduced the flare in a 4 mm. .95 N.A. objective by blacking the inside of the mounts near the front of the objective, which were brightly polished. He produced further photographs of a very fine pearlitic structure, and said he considered that, taken at 8,000 magnifications, was better than the corresponding photograph of the same field at ×1,500, as the details of the structure could be more plainly seen. A Zeiss × 12 compensating eye-piece was used in obtaining the photographs at 8,000 magnifications. He submitted photographs of a long distance fine focussing adjustment he had fitted to his Zeiss-Martens horizontal microscope, and found to be quite satisfactory.

Mr. J. H. G. Monypenny, referring to the capabilities of different stands, said he had never met one to equal the large "Works" model made by Watson. He had used one of these stands fifteen years, and it was still in perfect condition. He had tried a number

of other stands, including the Zeiss-Martens, but had not seen one to equal the Watson. Opinions differed as to the relative wearing qualities of British and German stands; there was no doubt, however, that the better quality British stands were good instruments, and would stand a great amount of use; at the same time they could be improved by using more suitable kinds of metal for the moving parts, such as pinions and racks.

With regard to objectives, the English achromatic lenses worked perfectly, providing they were used with yellow-green light, and with low and medium powers one could obtain results comparable with those given by Zeiss apochromats. For low power work they had the advantage of possessing a much flatter field than the apochromats, but they did not work well with blue-violet light. Some of the new apochromats made by Watson and Swift were, he believed, very good lenses, but he had not tried them. For the highest powers the apochromat was much superior to the achromat, though good results could be obtained with the latter.

Several remarks were made about fine focussing arrangements. Nearly all his work had been done with a vertical camera, and, being endowed with a rather long arm, he had not needed any extended arrangement for focussing. The arrangements he had seen have been rather a nuisance, and probably the worst was the one fitted to the Zeiss-Martens stand.

For very low power work he did not think any ordinary type of microscopic objective suitable if one required a large field. Some type similar to the Zeiss projection lens was much better; with such a lens one could easily obtain a field up to ⅝ in. diameter.

With regard to the use of prism or disc illuminators, in spite of what had been said, he believed the disc was very much better than the prism for high power work. Providing the structure was suitable and the detail in the section arranged in the right direction (that is, with respect to the prism), one could obtain very good photographs with the prism illuminator, but in most specimens, for example, of pearlite, the laminae were arranged at different angles in various part of the field, and it was impossible to arrange it so that each set of laminae was in the best position to be resolved. For low power work there was no doubt that the prism was superior to many individual discs on the market for the reasons given in his paper.

Reference was made in one of the papers to the impossibility of obtaining good contrast with medium power dry objectives, such as the 1/6th inch, owing to flare due to reflection of the incident light at the front surface of the objective. He had used a Zeiss 4 mm. apochromat for some years for metallurgical work, and found it quite easy to obtain sufficient contrast. It would be very inconvenient to have to use an immersion lens for such powers.

Several references had been made during the discussion to the various types of metallurgical stands. Many of the new fancy stands were no improvement on the old type, and very often they were much worse. In a metallurgical stand, the stage should have a coarse adjustment, but the fine adjustment should be on the tube. In any case, the milled head for the fine adjustment should not be fixed to a movable part of the stand (such as the stage), as, if so,

the flexure due to the pressure of the hand might be sufficient to affect the focus of a high power objective. In this respect it might be mentioned that when using a 2 mm. immersion objective of N.A. 1.40 a movement of $\frac{1}{50,000}$ of an inch along the optical axis was sufficient to put the field out of focus.

With regard to Dr. Thompson's remarks on the halo produced round the fine detail in photographs at very high magnifications, while agreeing that such halos were produced, he thought their width was rather less than stated by Dr. Thompson.

Mr. Birch pointed out that by the use of different screens photographs were obtained which seemed to represent two totally different things. The whole process of photography should be understood besides the optical system.

Dr. W. H. Hatfield said that with regard to the standardisation of magnifications in his laboratory, they had found it helpful to standardise to 10, 50, 100, 500, and 1,000 diameters. It would be very helpful in studying the work of other people if the photographs were of the same magnifications.

Mr. J. N. Greenwood: The question of the size of reproduction also arises.

Dr. W. H. Hatfield: I suggest that the matter is worthy of consideration.

The Chairman: Such standards have been laid down in America.

Mr. T. G. Elliot: Sir Robert Hadfield has taken a great interest in the question of standard magnifications for photomicrographs, and he long ago decided to use standard magnifications in his own research laboratory. He took a practical interest in the work of the Committee of the "American Society for Testing Materials," which was responsible for drawing up the report on "Magnification Scales for Micrographs," which has already been mentioned this evening, and several of his suggestions were adopted and are included in the revised report, published in June, 1918. In that year, too, Sir Robert endeavoured to get the British Engineering Standards Committee to take up the subject in this country. After due consideration, however, they decided against it, because they felt it would be impossible, at that time, to standardise the lenses to be used in obtaining the magnifications, without which the standardisation of magnifications would be useless. It was also thought that this matter and the related one of the full-sized reproduction of photomicrographs might well be left to the Publications Committees of the various Societies interested.

The Chairman said that in his laboratory they had adopted 100, 250, and 750 as standard magnifications.

Dr. F. Rogers advocated the adoption of round-number standard magnifications for reproduction and report purposes.

Dr. F. C. Thompson said it was at times very difficult to confine oneself to given magnifications. The Institute of Metals had brought out a list of magnifications seven or eight years ago, and authors of papers were requested to confine themselves to those standards, but no attempt appears to have been made by the Publication Committee to enforce these, and he did not think they were being observed now.

With regard to stands, in his experience the English stand was absolutely unsurpassed. They had some very old Beck stands at the University which had been subjected to extremely hard work, and even now those stands were in excellent condition. The same applied to geological and other stands by Watson's, which were being subjected to equally hard work. They appeared to be a distinct improvement on anything that foreign countries could supply.

With regard to objectives, the position was not quite the same. For lower power English objectives were most admirable, but he agreed with Mr. Monypenny that above one-sixth the Zeiss was much better. Dealing with illumination, the arc lamp, if it was working well, did quite admirably. Small arcs, however, were very unsatisfactory. If it were not for the increased amount of attention required, the ideal illuminant was the lime light. One got large area of illumination of high actinic value if one took the necessary trouble.

A Member remarked that if a standard for magnifications was fixed there should also be a standard of objectives for each magnification.

The Chairman: On this matter of standard magnification this Association might very well have the views of all our members using microscopes ascertained and a memorandum prepared.

Mr. F. S. Spiers said that an important factor in determining the size of reproductions was that of cost. Anyhow, that placed an added difficulty in the way of standardisation. With the permission of the meeting he would like to bring up the subject before the Council of the Faraday Society, and perhaps some steps might be taken in the direction of standardisation. There were one or two things mentioned in the discussion in London which he thought it of interest to bring forward, notably the suggestion to form a standing committee to undertake proper tests of objectives now being manufactured. It was hoped that would settle once and for all the question of the merit of British objectives.

The Chairman: It appears that members of our Association are not quite unanimous on certain points. In the first place, as regards the question of disc *versus* prism illumination. I may have been unfortunate in my experience of prisms, but I always find that I can get better photographs with even ordinary covered glasses than from any prism, and, judging not only by my own results, but by those of my friends, I must say the glass disc illuminator is much to be preferred to the prism. The other point on which there is a sharp difference of opinion is with regard to illuminants. I have

found the "Pointolite" extremely useful and, if properly used, it gives excellent results. It gives a very steady and strong illumination, and may be used for everything except screen projection, when the greater power of the arc lamp is required.

I think rather too much has been said to-night with regard to photomicrography, and too little about the use of the microscope for purposes of examination and study, especially at high powers. Actual research work is not done by examining photomicrographs, but by prolonged visual inspection of structures under the microscope. It is rather the tendency nowadays to take a photograph and hardly look at the specimen at all; but, after all, photographs are only imperfect illustrations necessary for reports and publications.

As regards the present indifferent construction of microscopes, I consider that it is for the metallurgical engineer, who should know what he really requires, to design the mechanical details of his microscope, leaving the optician only to deal with the optical system. Further, with regard to existing microscopes, I quite agree that English microscopes have been very unfairly condemned in comparison with Continental instruments, although as regards objectives English makers do not seem to be able to keep up to the same standard of excellence as Continental makers, but they occasionally turn out lenses which are as good as can be obtained anywhere. Then, as regards enlarged photomicrographs, I must say that I fail to see any point in enormously high magnifications obtained by this means. Such photomicrographs at, say, 5,000 diameters magnification, give no information which cannot be obtained from a photomicrograph at 1,000 diameters.

Dr. F. Rogers: As an enlarged photograph it is of some use.

The Chairman: Yes, as a picture for hanging on a wall. You can, of course, go up to enormous enlargements by the use of a lantern, but this only assists by permitting more people to see the photograph at one time.

Mr. T. G. Elliot: A photograph taken at 5,000 magnifications has this advantage over an enlargement, that before taking the photograph, you select your field at this magnification, and, as we say on page 5 of our paper, "we consider this an important point." We quite agree with Mr. Dickenson and other speakers who have criticised the use of very high magnifications, that nothing new has been learnt from them; although we submit that inasmuch as they do enable one to see the details of the structure easier, they have this important advantage over photographs taken at lower magnification. It was partly because Sir Robert Hadfield believed that we had got as far as was practicable with the apparatus available, that he suggested a Symposium on the Microscope, in the hope that it would focus attention on this point and lead to increased effort to obtain apparatus which would open up new fields of investigation.

Dr. F. C. Thompson, replying to the discussion, said that as the wave-length of light decreased the resolving power was increased. Up to the present ultra violet light had been unsatisfactory with metallurgical specimens, though there was no obvious reason why

this should be so. With regard to Mr. Monypenny's criticism of the diameter of the halos, he had formed his conclusions on the ordinary laws of optics, and there was no very obvious reason for departing from it.

Mr. J. H. G. Monypenny said he was quite in accord with what had been said with regard to magnification, that the limit is reached at 1,500 diameters. The only advantage in photographing above 1,500 (apart from photographs for reproduction purposes—in which case enlargement is sometimes desirable), might be in the case of a man whose vision was not as good as it might be, or who did not wish to tire his eyes examining every detail.

The Chairman, in concluding the meeting, said: We are very glad to have had the opportunity of discussing in Sheffield the papers on microscopy which were recently read before the associated Societies in London, and I think I may say that this Association is grateful to Sir Robert Hadfield for making the suggestion that such a further discussion should take place. If, and when, the Faraday Society has another Symposium on some other subject, this Association will, I am sure, be pleased to arrange for another joint local meeting on the lines of that held to-night.

ADJOURNED DISCUSSION IN LONDON.

April 21st, 1920.

The Royal Microscopical Society held a special meeting on April 21st, 1920, in the Rooms of the Society at 20, Hanover Square, London, W., in conjunction with the Optical Society and the Faraday Society, to discuss the papers presented to the Symposium which dealt with the "MECHANICAL DESIGN AND OPTICS OF THE MICROSCOPE."

Professor John Eyre, President of the Royal Microscopical Society, who was in the Chair during the first part of the proceedings, opened the Discussion with the following remarks:—

The object of our meeting this evening is not to initiate a fresh discussion on the microscope, but to continue the work which was commenced at the Symposium held in January last. The volume of communications which was simply poured upon the Symposium was so great that it was impossible to discuss more than a very few of them, and, indeed, many papers were only presented in abstract, but in order to correlate the views of all the workers in this branch of science, we are arranging a series of short meetings in which specially selected papers can be discussed, and the results of the discussion recorded for publication. During the course of the evening my two confreres, Sir Robert Hadfield, President of the Faraday Society, and Mr. R. S. Whipple, President of the Optical Society, will each take the Chair for a period, in order that the members of their Societies may feel that they are adequately represented.

The Chairman then called upon **Mr. J. E. Barnard** to give a GENERAL SURVEY of the subject (*see* page 37), after which abstracts of the following papers, read at the original meeting, were presented by their respective authors:

THE MECHANICAL DESIGN OF THE MICROSCOPE.

(*a*) *General.*

PROFESSOR F. J. CHESHIRE, C.B.E., "The Mechanical Design of Microscopes."

MR. CONRAD BECK, C.B.E., "The Standard Microscope."

MR. F. W. WATSON BAKER, "Progress in Microscopy from a Manufacturer's Point of View."

MR. POWELL SWIFT, "A New Research Microscope."

(*b*) *Metallurgical.*

Dr. W. Rosenhain, F.R.S., "The Metallurgical Microscope."

Professor Cecil H. Desch, D.Sc., "The Construction and Design of Metallurgical Microscopes."

Mr. E. F. Law, "The Microscope in Metallurgical Research."

Mr. H. M. Sayers, "Illumination in Micro-metallography."

(*c*) *Petrological.*

Dr. J. W. Evans, F.R.S., "The Requirements of a Petrological Microscope."

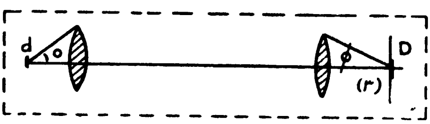
Sir Robert Hadfield, F.R.S., in taking the Chair during the reading of the metallurgical papers, said:

I do not intend to take up much of your time, but should like to say in a few words how very gratified I feel to see this important gathering continuing the work we tried to do a couple of months ago. We then had something like 40 papers presented, and as, of course, it was quite impossible to do more than touch upon the fringe of the discussion of them, I may also add that out of that large gathering in the Rooms of the Royal Society we have had a continuation of the same work in the cities of Sheffield and Glasgow. That will show you that we did really stir up not only the metropolis, but also the north and the far north. As I am taking the Chair during the reading of the papers in the metallurgical section, I would like to say how very important we find the microscope as regards metallurgical operations and investigations. My friend Mr. Barnard has said that we do not think sufficiently of resolution and that we are rather too fond of magnification. I still have a little feeling for magnification, but cannot help thinking that we shall, aided by resolution—the double resolution of the microscope and our own resolution—find out improved methods of handling steel. That is a matter I am specially interested in. The more one studies the structure of iron and steel, the more fascinating it becomes. To use an illustration in which I have been concerned very much during the war, *i.e.*, the production of the large calibre armour piercing shell, we could not really have obtained a shell of the requisite quality without the use of the microscope. When one considers that the 18-inch gun carried a projectile with a muzzle energy of 150,000 foot-tons, one can imagine the tremendous stresses which occur when that shell is suddenly brought to rest by the armour attacked, and yet it must not break. Out of those war researches are proceeding further investigations which will apply that information to the arts of peace, and I do not think it will be found that we have wasted our time. We in England were not behind, but we wanted stimulating a little, and a great deal of investigation work was carried out during the war which would not have been done otherwise, because in times of peace the money could not be found.

DISCUSSION.

Commander M. A. Ainslie, R.N.: With regard to design, the principle of the optical bench seems to me exactly the principle needed in order that you may build up in bits the apparatus you want for any particular research, so that everything may fall naturally into alignment. Each piece of apparatus should be on a separate saddle of its own. I would even have the eye-piece on a separate saddle; with a separate coarse adjustment of its own; this may sound revolutionary, but I believe it to be perfectly sound. Then, again, I think we ought to have a longer range to the draw-tube; as a rule, it is quite insufficient, especially when high power dry objectives are in use. An ordinary dry 3 mm. objective requires a change of about 20 mm. in the tube-length to compensate for a change of .01 mm. in the thickness of the cover glass; and although objectives of lower power are less sensitive, objectives of low power and large aperture are not very easy to obtain.

With regard to the size of illuminant required in photomicrography, whether of metals or of other objects, this is settled by a very simple relation. If d be the diameter of the light-source, and D that of the illuminated area on the object slide, and if θ be the



angle made with the axis of the extreme ray entering the optical system and ϕ that of the extreme ray falling on the object, the latter being supposed in a medium of refractive index μ, then we always have

$$d \sin \theta = \mu D \sin \phi,$$

which is, of course, merely the well-known "optical sine law"; it really amounts to saying that the product of the diameter of the light-source into the N.A. of the collecting lens is equal to the diameter of the circle of illumination on the object, multiplied by the N.A. of the condenser. You cannot get away from this relation; it settles once for all the diameter of the illuminated field, and it is true for any optical system whatever between the light-source and the condenser.

If you are going to use a metal filament lamp, you are confronted with one of two things; either you are going to project an image of the filament on your object, or else you are going to project this image into the plane of the objective aperture, filling it irregularly; a state of things which Professor Conrady long ago showed to be incorrect. The diameter of the filament is far too small, having regard to the relation I mentioned just now; and of course one does not want an image of the filament on the photograph.

With regard to the intensity of the arc, what decides the exposure is the intrinsic brilliancy and not the total power of the arc. As to the heating effect, I have used a 25 ampere arc within

$1\frac{1}{4}$ inch of one of the solid glass rods supplied by Messrs. Beck, for half an hour at a time, without the slightest damage to the glass, and I am inclined to think that this "bogey" of the danger to your collecting lens is somewhat over-rated.

Mr. C. Beck: Has Commander Ainslie tested the amount of light lost by absorption from glass to glass. Is it 75 per cent.?

Commander Ainslie: Yes, of course, a great deal of light is lost. It was a question of the capability of the glass to withstand heat. It is a question of the size of the illuminant. I have seen a piece of ground glass as the source of illumination instead of the crater of the arc itself.

Mr. Maurice Blood: You can use a large collecting lens.

Commander Ainslie: But you will not get more light, because it is the intrinsic brilliancy of the light that counts.

Dr. R. Clay: The feature that pleases me most in the microscopes that Mr. Beck has shown is the provision that he has made by which one can start with a simple form and gradually build it up. I have been advocating this for some time, and I am very glad to see it is accomplished here. That a student who has not too much money can commence with an inexpensive instrument and add to it as he goes along, and as he feels the necessity for and understands the use of improved apparatus, is a very great advantage.

I was very much interested in Commander Ainslie's formula connecting the area illuminated by a substage condenser and the aperture of the condenser. I think it is one of the most important things that has been brought forward during this Symposium, because there is quite a lot of nonsense talked about the illumination of microscope objects, and that formula puts the whole in a nutshell. I was also interested in the paper on the illumination of metallurgical specimens, as I think it is possible with a prism that I devised some time ago for another purpose to give the 50 per cent. illumination that has been asked for in that paper.

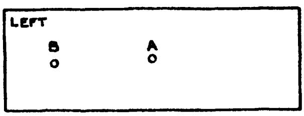
Mr. W. R. Traviss: I should like to mention that it is over 35 years ago since I introduced to Messrs. Swift and Son a microscope on the lines of the one that the last speaker has said he would like to see, viz., an instrument that could be commenced in a small way and gradually built up as time goes on.

The simplest form had a firm tripod, of which the toes of the legs were cork-filled to give firmness. The stage was a cut-open form recommended by the late Dr. Dallinger and Mr. E. M. Nelson. The coarse adjustment was made by the body sliding in a cloth lined fitting. The screwed holes for the attachment of the limb or arm to the stage were made a standard distance from the optical centre, so that a coarse adjustment with rack and pinion movement could be exchanged. The side edges of the stage were grooved for the vertical movement of a mechanical stage or roller sliding bar which

could be easily slipped on and off. The under-stage tube was fixed to a plate; this could be replaced by a centering motion, rack and pinion sub-stage. The sliding draw-tube could be replaced with a rack and pinion draw-tube divided into mm.

Another addition which is added to a small portable microscope, and would be useful to all plain stage microscopes, whoever the maker might be, is a very simple and efficient finder, and is standardised as follows:—

Each maker has a 3 × 1 in. piece of metal 1 mm. thick. At equal distances from the ends and sides is made a small hole (A) 1 mm. diameter, and another hole the same size, made exactly 1 in. distance from the centre hole and equal distance from the sides (B), thus:—



When an instrument is assembled and completed ready for sale the above plate is placed on the stage of the microscope resting against the sliding bar or mechanical stage, or a mechanical square; then with a 2/3rd or 1 in. objective the hole A. is brought into the centre of the field of the eye-piece; the metal 3 × 1 is held firmly by the stage springs or clips, and a small sharp drill is passed through the hole B and a few twists given, which will make a drill mark on the stage. This is then filled in with Plaster of Paris, thus giving a white dot over a black stage.

Now suppose we have a scattered slide, and some part (or parts) has some object of special interest which one wishes to find quickly at some future time—all that is needed when the object is squarely on the stage is to make an ink dot on the slide exactly over the white dot on the stage. Other dots can be made if needed, and marked A, B, C, etc. Then for the future all that is necessary is to place dot A, B, or C over the white dot on the stage, and the desired part is in the centre of the field of the eye-piece.

With regard to Dr. Evans's paper, he has specially mentioned crystals, but I do not think any instrument is so efficient for examining minute crystals as the one introduced by Mr. Allan B. Dick. In this instrument you can introduce a minute crystal on the cross wire, and it does not alter its position at all.

Dr. J. W. Evans: No one appreciates more than I do its valuable qualities, but it is impossible to apply the methods devised by Professor Beck for the study of interference figures to a microscope with rotating nicols, at any rate without very considerable modification, and in the second place the small upper Bertrand lens cannot compare in convenience and effectiveness for the examination of the interference figures of minute objects with a Beck lens placed above the eye-piece, in conjunction with a diaphragm placed in the focus of the latter.

Col. J. Clibborn: We have heard to-night an immense amount of detailed information as to what is desirable, but nobody has suggested yet the means by which we may attain our object. I do not think there is any doubt that what is desirable is that we should, at all events, have one standard microscope which will fill the conditions that have been mentioned. We should at all events have one pattern—it is possible that we may require other patterns—but we at any rate require one pattern of standard microscope, because it is only possible to manufacture in very large quantities. These instruments cannot be manufactured cheaply, even in large numbers, unless you have suitable machines, and the question is how are we going to arrive at this condition of things. I do not think it can be done by separate manufacturers, because it is not possible that the patterns will all agree. The manufacturers might all join together and form a combination, and perhaps it might be done in that way, but I think the best way is what I suggested 12 months ago, namely, that a Committee should be appointed of the ablest men interested in the question, inside and outside the Society, to devote themselves to the design of the standard microscope. It should undergo as much criticism as can be brought to bear upon it, and then we should endeavour to get an instrument made and tested. If we do not, I am perfectly certain that the manufacture of the microscope will leave this country and go to the Continent.

Dr. J. R. Leeson: An important question is that of price. I have been trying for four years to fit up my little laboratory with microscopes, but I cannot get them; at least, if I can get them I cannot find the heart to pay for them. Scientists are not rich people, and if you are going to popularise the microscope, you must have an instrument that is within the reach of the ordinary individual. If you do not, then the trade will again leave this country.

Dr. R. Mullineux Walmsley: The last speaker and the last speaker but one have referred to matters with which I have been somewhat associated through the British Science Guild. A Committee has been proposed here to-night, but I would like to inform the proposer that the work he suggests has already been done. The British Science Guild first of all invited well-known users of microscopes to schedule their requirements. Having collected and collated these schedules, we asked the manufacturers to join the Committee and tell us whether it was possible from their point of view to produce microscopes which would fulfil their requirements. Eventually by the combination of the scientific men who were using the microscopes and of the manufacturers, we drew up and published specifications for three or four standard instruments for different purposes. We were in the middle of the Great War at the time, and the object was to see whether manufacturers would consider placing such instruments on the market, when peace came, with such added modifications as the progress of time might render desirable. The question of price was not overlooked, although I do not know that the prices we put down in 1917 can be held to at the present time.

The evidence of the work is on record, both in the *Journal of the British Science Guild* and the Royal Microscopical Society, and I fancy that the manufacture of both instruments exhibited to-night were to some extent influenced by the specifications prepared by the Committee.

Mr. Conrad Beck said that the standard instrument made by his firm was made to the specification of the British Science Guild Committee, but the larger one, made by Messrs. Swift, was quite a different matter. The latter was more of a special research type. He certainly welcomed the suggestion that a small sum of money should be put up to assist in manufacturing microscopes. But what was meant by a small sum? In some instances upwards of £20,000 had been spent in tools and machinery; Messrs. Watson and his own firm had each expended an enormous amount of money on machinery and tools which it was hoped in course of time would be found advantageous to microscopical work, and if a small sum meant something of this nature it was an excellent proposition.

Mr. Watson Baker: The microscope which our firm has made according to the specification of the British Science Guild is not here to-night, but I am glad to take this opportunity of saying that we should welcome any members of the Royal Microscopical Society to our works to see exactly what is being done.

I believe that Col. Clibborn himself would be pleased to see that microscopes are being made by machinery in a manner not hitherto done in this country. It has taken us 12 months to put up a new building and make the necessary tools, but we have accomplished it, and if British users could be induced to visit us and see what we have done and what it has involved, we should be very pleased.

Mr. Perkins: I was struck by the remark of Professor Desch in his paper when he said that microscopes wear because of the bad material of racks and pinions. I have found in a fairly long experience of microscope repair that sometimes the German slides are softer than the English slides, so that does not, in my opinion, account for the fact that the English microscope wears quicker than the German. It has always seemed to me that the English makers, in spite of their undoubted ability, overlook the fact that if you want to reduce wear on the slides of a microscope, they must bear properly upon each other. It is no good putting in slides which bear at points, as in Fig. 1. Wear very quickly takes place at those points and develops a shake, and you get a loss of stability, such as Professor Barnard spoke of. The closest analogy I can put forward is an ordinary bearing. If, for argument's sake, the inner bearing is much smaller than the outer (Fig. 2), you get point metal to metal contact and quick wear. If, however, it fits as in Fig. 3, the lubricant stops in in an unbroken film, and you get long and efficient wear. I have seen microscopes 20 years old which have no shake in them and still fit perfectly all over. Then, again, the weakness of design of the usual spring fitting is another point which

in my opinion English manufacturers have always overlooked. If you spring at four corners, like *a*, *b*, *c*, *d* (Fig. 4), the fitting E has got to be a very fine fit, and also the fitting F, but directly you start springing E you distort F at once. I have seen it; I have spent hours over it worrying about it, but English makers are

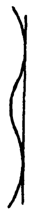


Fig 1.

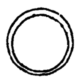


Fig 2

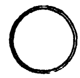


Fig 3

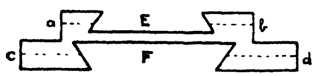


Fig. 4

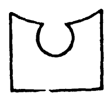


Fig 5

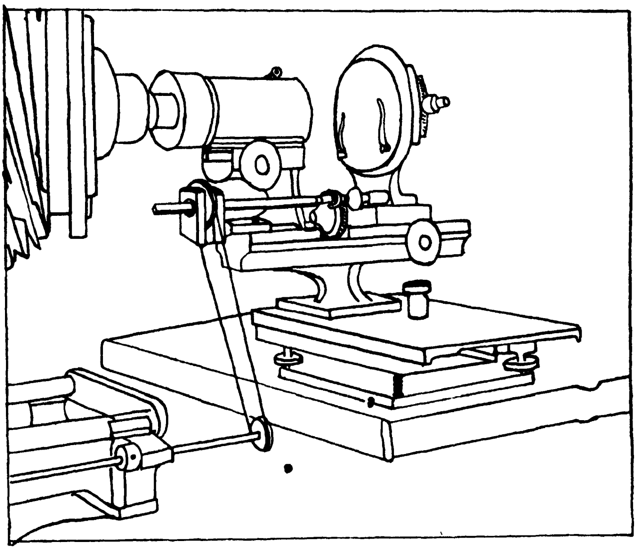
gradually waking up to the fact that you have got to have your slides in a springless chunk of metal, something like that shown in Fig. 5, so that when you do the screws up, the chunk of metal remains as it was and does not distort. Again, how can you efficiently remove the grinding material from the springing slots, which is another obvious source of wear.

Mr. Beck: Was the microscope 20 years old which you referred to German or English?

Mr. Perkins: It was German. I am not saying that I have not seen an equally good English instrument 20 years old, but I am speaking of English instruments as a body. Another point is that English makers must now see to it that they have an efficient system of inspection. The Germans have a very efficient system of inspection, and English makers must see that nothing leaves their factories which is not perfect. When you have got to that point, but not before, then success is assured.

Mr. Harold Wrighton: It fell to my lot to prepare the photomicrographs which were shown in the paper given by Sir Robert Hadfield and Mr. T. G. Elliot at the Symposium. These photographs were taken on a Zeiss-Martens horizontal machine. In order to obtain them I found it necessary to alter radically the long distance fine focussing adjustment. Even in the best patterns of photomicrographic apparatus the design and efficiency of this long distance focussing fittings seems to receive very little attention. Possibly a description of the new arrangement may be of interest to some gentlemen who have a similar Zeiss-Martens outfit.

The arrangement shown in the accompanying sketch was made in the works at very small cost, and has proved very satisfactory. The short metal rod which fitted into the socket on the focussing rod has been replaced by a longer rod, $\frac{1}{4}$ in. square in cross section. A $1\frac{1}{2}$ in. pulley wheel, turning on flanges, is mounted on a bracket at the corner of the microscope base. A square hole through the pulley wheel is just large enough to allow of very slight play between the wheel and the square rod. As the square rod will pass along through the pulley wheel, horizontal traverse of the microscope stage is not interfered with. A long rod is mounted in brackets screwed



to the base, which carries the camera. This rod has a $\frac{3}{4}$ in. pulley wheel at one end, which is connected by cord to the other wheel. At the other end is a 2 in. milled brass head, for turning. The two grooved wheels over which the cord passes are milled inside the grooves, thereby preventing slip. The arrangement as made to dimensions given above further reduces the speed of fine adjustment by one half. The main advantage is that, owing to slight play between wheel and square rod, any slight torsion produced whilst turning the rod can ease itself when the hand is removed, without turning the fine adjustment and disturbing the focus.

Another matter, referred to by a previous speaker, is the lack of contrast in most metallurgical specimens as compared with a biological section. This is one of our difficulties, and, as a matter of fact, most of our photomicrographs show considerably more contrast than is actually present in the specimen.

Mr. T. Smith: I would like to have spoken on the optical side of the discussion, but there is one matter I will refer to. We have been given some figures by Commander Ainslie based on a displacement of 1/100 mm., and some further results on a basis of the same magnitude, with the displacement along the axis, may be of interest.

I have worked out some figures relating to a 2 mm. objective. N.A. = 1.4, which gives perfect definition when used properly. With the object displaced 1/100 mm. from its proper position, I find that the marginal rays, instead of converging to the paraxial image point, get farther and farther away from the axis. This indicates how accurately it is necessary to focus at high magnifications. Therefore I would like to suggest that manufacturers of apparatus for high power work and particularly for ultra-violet microscopy should pay special attention to the problem of adjusting the specimen accurately in relation to the objective. Particularly when short wave-lengths are being used, as in ultra-violet microscopy, is this necessary if much time is not to be wasted in taking useless photographs.

The Chairman: We now proceed to the discussion of the OPTICS OF THE MICROSCOPE, and I will ask MR. WHIPPLE, President of the Optical Society, to take the Chair.

Mr. R. S. Whipple: I think that at this stage of the proceedings we ought to congratulate Messrs. Beck on the fact that they have been able to produce a standard microscope and that they have been able to keep their promise to produce it this month. As a manufacturer I know the difficulty of keeping a promise of this kind, and it is greatly to their credit that they have been able to keep to time. As a manufacturer, I also know some of the difficulties involved in the production of a new instrument. They have covered the foot of the stand with ebonite. To do this is in itself an achievement; they have introduced this ingenious geometric arrangement for holding the objectives, another considerable achievement. Thus in this apparently simple looking article there are a number of mechanical achievements—I venture to say great achievements—which a few years ago would have been regarded as impossible. I think, therefore, that it is not right to pass from the mechanical side of the microscope without expressing our indebtedness to them for what they have done so far, and to wish them and other English microscope makers every success in the future.

Abstracts of the following papers were then presented:—

THE OPTICS OF THE MICROSCOPE.

PROFESSOR A. E. CONRADY, "Microscopical Optics."
DR. H. HARTRIDGE, M.A., "An Accurate Method of Objective Testing."
MR. H. S. RYLAND, "The Manufacture and Testing of Microscope Objectives."
MR. F. TWYMAN, "Interferometric Methods."

DISCUSSION.

Mr. Conrad Beck: I have been greatly interested in the Hartridge test for microscope object glasses. Whether the graphs that you get are any value or not, it is impossible to say. I should not at present like to express the slightest opinion; all I can say is that I was interested to find that the graphs which we took in succession

one after the other with the same object glass were fairly consistent, which, considering the conditions under which these observations are made, is rather remarkable, because one is using an extremely small portion of the object glass at one time. The principle is that by the use of a small diaphragm you are illuminating a small zone of the object glass, and the numerical aperture of the portion you are illuminating is very small. I did not expect that our results would agree, because of the extremely inferior image produced with such a small portion of the object glass being used at one time. In discussing this matter with Dr. Hartridge, he pointed out that his microscope was not nearly sufficiently rigid for the purpose. The matter has been considered by my firm, and they came to the conclusion that there was no microscope sufficiently rigid for the purpose, and consequently for the last eight weeks we have been designing an instrument which I am proposing to make for my own personal use that I hope and think will be the most perfect microscope stand ever made. I shall show it to the Society as soon as it is made. Those who use the microscope for general work may consider it too elaborate and expensive for ordinary purposes, but I am not sure. It will have some features about it that will make it unusually rigid. Its construction is an interesting engineering problem, and whether anybody will ever order a similar one may be doubtful, because the cost will be very great.

There is one point made by Dr. Hartridge in his paper which I think is an obvious error, and if it were pointed out I think he would admit it. The method of testing the object glass is only a test to see whether the light from a lens is going to one point. It is not a test of the sine condition. That must be carried out as a separate test, and I am bound to say that my own impression is that when the Hartridge test is worked out and his method of calibrating and plotting out has been done, we shall find we are testing an important, but not by any means the most important, correction on an object glass. The important points about an object glass, apart from achromatic corrections, are firstly, that the light from the whole object glass shall go on to a point, and secondly, that the focal length of every zone in the glass shall be the same, and it is this latter point that the sine condition guarantees. Mr. Hartridge's test has some analogy to the Hartmann test; it measures the lateral shift of the uncorrected rays instead of the longitudinal error.

Commander M. A. Ainslie, R.N.: I should like to concentrate attention on the subject of the condenser. Professor Conrady refers to the incorrect position of the iris diaphragm; this is certainly most marked, but there are one or two points to be considered in this connection. There is no reason why the iris diaphragm should not be placed between the top lens of the condenser and the next lens, or perhaps a little lower down; at any rate, much higher up that it is at present. The diaphragm could be very well worked by means of a bevel wheel and a pinion coming out radially; the only thing against this is that the stage is so thick. It would be quite impossible on the standard instrument here shown, but if we were to return to the "horseshoe" type of stage designed by Nelson, it could be done perfectly easily. Presumably, however, the exit pupil of the objective is in the neighbourhood of its upper focal

plane; as a general rule I fancy it is rather lower down, but the position does not seem to be constant, even in objectives of the same type. If the obliquity of illumination at the margin of the field mentioned by Professor Conrady is to be avoided, the iris will have to be in the back focal plane of the condenser; if that is the case, no lateral movement of the condenser will affect the position of the image of the iris-aperture in the back lens of the objective, and it will be impossible to judge of the centering by looking down the tube.

Again, I think that both opticians and users of the microscope are content with too little in connection with the performance of the condenser; and I should say that the objection that the slide is composed of " window glass " introduces another " bogey." The area involved is always small, and if an oil immersion condenser is used, the surfaces of the slip cease to exist optically. At any rate, with a first rate modern achromatic condenser, such as the Watson " Parachromatic," it is possible, when the light source has a screen extending half way across it, to focus with such sharpness an image of the edge of this screen on the object that one row of dots on, say, *Pleurosigma Angulatum* shall be in full light and the next in " full darkness "—and this with an N.A. in use of not less than 0.7. This means that it is possible to get sharpness of the order of $\frac{1}{50,000}$ of an inch. But this is only done on one condition, and that is that the distance of the light-source is carefully adjusted to the thickness of the slip; as carefully as we adjust tube-length to the thickness of the cover glass. This point is almost universally avoided by the text-books, and I want to bring it forward as strongly as possible.

Mr. T. Smith: With regard to increasing the resolving power of microscope objectives, there is little doubt that the numerical aperture, as it is ordinarily understood, can hardly be increased with advantage, but there is considerable prospect of obtaining increased resolving power by using shorter wave-lengths of light. There are very considerable difficulties at present in the way, but I see no reason why they should not be overcome, although an extraordinary amount of experimental work will be involved. It is necessary to know the properties for such light of a very great variety of materials. Where we already possess some knowledge of the behaviour of certain materials with regard to ultra-violet light, this information must become much more precise than at present before it can be considered adequate, and I should like to see some definite encouragement given to researches of this character, because they can hardly fail to lead to results of value to the microscope user. Coming now to objectives and their design, it seems to me that this subject has never been investigated systematically, but that new objectives have generally been a further development of old designs on known lines. I should like to see systematic investigations undertaken, so that we may know what prospect there is of effecting real improvements in the corrections. For example, in a high power objective we have a lot of lenses placed very close together, though I am not aware of any thorough investigation which justifies adherence to this arrangement. There are obvious difficulties in the way of large separations; nevertheless, there would appear to be some decided advantages to

be gained. At present with apochromatic lenses the curvature of the field is due to the properties of the transparent materials we employ. In general they have very similar properties as regards relative dispersion, and this imposes very severe limitations on what can be achieved; but these limitations no longer hold if the lenses are well separated, and it is possible that material improvements may be effected by radical alterations in the type of objective. There would be difficulties in doing this with objectives for ordinary use, but they would hardly apply at all for a special instrument required to give very great magnification, such as the metallurgists ask for, and I think these investigations might very well be made in regard to objectives for this particular purpose. In fact, I think we want to see a very great deal more of the design and manufacture of objectives for special purposes instead of expecting one objective of a given focal length to do any and every job. It ought to be realised more generally that an objective of high resolving power differs markedly from a so-called universal objective like a photographic anastigmat. A microscope objective of large N.A. is necessarily a very poor instrument for any conditions but precisely those for which it is designed. There are many other points to which attention might be called, but it must suffice now to mention one. A great deal has been said about the variation in the definition given by similar objectives made by the same firm from similar glass, which ought therefore to be identical in performance. I want to suggest that a possible contributory cause may be insufficiently accurate centering of the surfaces. I do not think that investigations have ever been carried out on methods of getting surfaces centered to an extraordinary degree of accuracy, yet a very high degree of accuracy is obviously required in a microscope objective. I have seen photographic lenses under examination with the interferometer, and these have shown marked irregularities in the wave front towards the periphery of the lens. When we seek the highest possible resolving power, it is the periphery of the lens that is all important, so I think we want to see, among other things, an investigation into methods of getting surfaces centered, not twice as accurately as we do them at present, but perhaps 10 or even 100 times as well. If any manufacturer were able to effect such an improvement, he would probably find that his lenses would realise a much more uniform standard of excellence than those produced at the present time. I very much hope that in some of the directions I have indicated the National Physical Laboratory may be able to give assistance to our own manufacturers.

Mr. J. E. Barnard: Mr. Smith has just referred to the question of investigation by the use of radiations of short wave-length. I should have hesitated to bring the subject up again had it not been that Professor Conrady also referred to it in his paper, and by a curious chance he has dropped into a not unusual error. He says that the limitations of the work are in part laid down by the opacity of bodies to ultra-violet light. When you get down to the dimensions with which we are dealing in a microscopic object which is at or beyond the ordinary resolution limits, opacity is almost nonexistent. Sir George Beilby has shown that very thin metal films

are almost perfectly transparent, and yet metals are the most opaque of substances. Latterly I have been endeavouring to photograph by means of ultra-violet light some exceedingly small organisms, some of which are beyond the limits of resolution, and the difficulty has been that with any wave-length I have at present available, the organism is transparent. The radiations pass completely through, and I am unable to get an image of any description whatever. So that to say that the limitations of the work are largely governed by the opacity of small bodies is not in accordance with practical experience or theoretical expectations. It may possibly arise if we use radiations of much shorter wave-length than those at present available, but in that case we shall be working with a microscope *in vacuo*, and I do not think it is a point which is likely to arise in practice for some time to come, although it may, and probably will, arise at a later stage.

Mr. L. C. Martin: I was interested in the description of the Hartridge test for the microscope objective, but I should like to say that it is not often, I believe, that a man testing a microscope objective wishes to know the aberration to any great accuracy, but rather whether the microscope objective is sufficiently good for the purpose. Therefore a somewhat easier quantitative test is to be desired. At the present time I have been doing a certain amount of work as a sort of preliminary study of the star test, and I think that possibly the so-called Rayleigh condition of less than one quarter wave-length a speedy test of the aberrations of a microscope objective.

Professor Conrady remarks in his paper that the fulfilment of the so-called Rayleigh condition of less than one quarter wave-length difference of optical paths between paraxial and marginal rays in good telescope and microscope objective, has been demonstrated by the Hilger interferometer. It is easy to understand that, imagining a perfectly spherical mirror in the interferometer and a means of controlling the position of such a surface to correspond with any particular focus of the test lens, such a perfect demonstration could be given. It is not easy to understand, however, when we consider that the errors of the surface of a mirror, which may be of the order of $\frac{\lambda}{4}$ or even more, are doubly important in such a case, and that the position of the test focus has to be obtained by trial. It is only when we consider a fact which was hinted at by Lord Rayleigh in 1879, and worked out by Professor Conrady in his paper on Star Discs, viz., that the effects of spherical aberration can often be countered very completely by changes of focus (or in mathematical language that we can partly balance the terms of the fourth and higher orders in the aberration expression by a change of the coefficient of the second order), that we can realise that the indications of the interferometer are trustworthy even to the extent previously indicated. It is necessary to bear in mind, however, that there is nothing magically sensitive in the interferometer tests as compared with star tests, for example, if these are performed with the maximum of care. Those who expect them to give tremendously sensitive results far excelling all other tests are doomed to disappointment.

Mr. Beck: Will you explain to us whether a quantitative measurement is obtained in the star test. The star test has been in use with the microscope objective ever since the achromatic microscope objective was known, in the form of a minute mercury globule reflecting a small source of light which makes practically an artificial star.

Mr. Martin: The work I have been doing is in a very unadvanced stage, but I hope it will be possible to obtain a rough estimate of the variation of the spherical aberration.

Commander Ainslie: I had the curiosity to test a low power objective on the well-known Wassel method, and it was easy to obtain (by this particular method of the extinction of the two sides of a zone simultaneously, with a screen), numerical values for the different foci of the different zones. I was only using a low power objective, an half-inch apochromat, and it would be difficult with high powers, unless, perhaps, an auxiliary telescope is used.

Mr. T. Smith: Mr. Beck said that the Hartridge test would not give coma. May I suggest that it is quite easy to get coma by plotting the spherical aberration for two somewhat different magnifications. From these numerical values, the deduction of the coma is quite easy.

Professor Eyre, in bringing the discussion to a close, said:

The time has now come when I must close the meeting. It is very difficult at the end of an evening o this character to sum up with anything like precision or to offer an opinion that has any value on the work that has been presented. There is, however, one outstanding feature, namely, that workers are willing and anxious to state their requirements to the manufacturers, and I think we have evidence that the manufacturers on their side are willing to do all in their power to help meet these needs. We cannot expect perfection at once. As Mr. Watson Baker has said, it has taken quite a year to get his factory and the machinery ready. It has been the same with all manufacturers and I do trust now that the necessities of the workers have been placed clearly before the manufacturers that we shall soon reach a stage when we shall have an instrument of our own manufacture, not only for home use, but one which will also enable us to capture the world's trade in microscopes.

APPENDIX I.

Catalogue of Exhibition,

Held in connection with

THE SYMPOSIUM AND GENERAL DISCUSSION

ON

The Microscope: Its Design, Construction and Applications,

On Wednesday, January 14th, 1920, in the Rooms of the Royal Society, Burlington House, Piccadilly, W.1.

GROUND FLOOR.

A SELECTION OF MICROSCOPES FROM THE COLLECTION IN THE SCIENCE MUSEUM, SOUTH KENSINGTON.

Lent by the Board of Education.

The instruments selected are arranged in chronological order, and illustrate the development of the compound microscope from the end of the sixteenth century until towards the middle of the nineteenth century.

Jansen's microscope (1590) is represented by a facsimile copy, and Hooke's microscope (1665) by a photograph of the Plate in his "Micrographia."

The rest are chiefly examples of the work of the leading English opticians of the eighteenth and early nineteenth centuries, viz., Marshall, Culpeper, Cuff, Martin, Adams, Mann, Watkins, Bleuler, Dollond, Smith, Ross, Powell, Tulley, and Pritchard.

To mark the introduction of the apochromatic objective a microscope by Zeiss, made in 1888, is also shown.

These instruments, which are not the property of the Board, are exhibited by permission of the owners, Mr. Thomas H. Court and Mr. Edward M. Nelson.

Descriptive labels are shown with the instruments.

LIBRARY.

(First Floor.)

MR. CHARLES BAKER.—Demonstration of photomicrographic apparatus, equipped for metallurgical research work, ultra-condenser, concentric dark ground illuminator, and recent introductions of new microscopes and objectives.

MR. A. C. BANFIELD.—Thirty glass transparencies illustrating the application of the microscope to low power stereoscopy. The subjects shown range in magnification from four diameters to seventy.

MR. J. E. BARNARD and MR. F. WELCH.—Quartz and glass mercury vapour lamps as illuminants for the microscope.

PROFESSOR W. M. BAYLISS, F.R.S.—

(a) Ultra-microscope of Siedentopf-Zsigmondy pattern, showing Brownian movement in colloidal gold.

(b) Heating chamber for use with "cardioid" condenser, showing cessation of Brownian movement on gelatin.

MESSRS. R. AND J. BECK, LTD.—The Beck Standard London Microscope to specification of the British Science Guild. Sloan object changer. High-power dark ground illuminator. Beck micrometer eye-piece.

MESSRS. BELLINGHAM AND STANLEY, LTD.—Instruments for measuring refractive indices.

Improved Abbe refractometer; all British design, enables refractive indices of solids or liquids to be determined at average accuracy of two units in the fourth place. The partial dispersion C—F can also be measured. The immersion refractometer shown is identical in principle, but is designed for use with liquids, being suitable for alcohol determinations. Refractive index plays an important part in microscopy, not only for materials used in objectives, but also in the case of various mounting media.

MESSRS. BOOTS' PURE DRUG COMPANY, LTD.—The use of the microscope in pharmacy and pharmaceutical chemistry.

MESSRS. BRITISH COLLOIDS, LTD.—Colloidal suspensions under dark-ground illumination, to show Brownian movement.

MESSRS. BRITISH DYESTUFFS CORPORATION (HUDDERSFIELD), LTD.—Dyestuffs used for staining.

Basic Colours:—
- Auramine O.
- Bismarck Brown R.100.
- Magenta Crystals.
- Malachite Green Crystals A 25 per cent.
- Methyl Violet 2B.
- Methylene Blue 2B.

Acid Colours:—
- Nigrosine G. Crystals.
- Orange G.

MESSRS. THE CAMBRIDGE AND PAUL INSTRUMENT COMPANY, LTD.—Reading microscope. Microscope used in the accurate cutting of screw threads. Microtomes.

MESSRS. CHANCE BROS. AND COMPANY, LTD. (MR. F. E. LAMPLOUGH).—Optical glass.

MR. A. CHASTON CHAPMAN, F.I.C.—Some cultivated and "wild" yeasts in pure culture; the former are used for brewing and distilling purposes; some of the latter are frequently a source of trouble in the brewery.

MESSRS. CO-OPERATIVE WHOLESALE SOCIETY, LTD. (DR. GEOFFREY MARTIN, F.I.C.).—The use of the microscope in the preparation of foodstuffs.

MESSRS. COURTAULDS, LTD.—The use of the microscope in the textile industry.

Exhibit A.—Samples of artificial silk and cloth, and microscope with sample of cloth under low power, illustrating employment for studying character of textiles.

Exhibit B.—Microscope with sample of natural souple silk stained blue, illustrating identification of fibres.

Exhibit C.—Microscope with cross-sections of modern viscose artificial silk, and photomicrographs showing differences in cross-sections of typical artificial silks, illustrating identification of origin and method of manufacture.

MESSRS. F. DAVIDSON AND COMPANY.—The "Davon" patent super-microscope and optical bench for direct visual observations under high power, large field and great "depth of focus," and embodying a new method of photomicrography.

MR. D. FINLAYSON, F.L.S., AND MR. RAYMOND FINLAYSON, F.R.M.S., F.Z.S.—The microscope and its uses in seed analysis. Identification and comparison of different species of seeds and their adulterants, by means of a revolving disc attachment to stage of microscope.

THE GEOLOGICAL SURVEY AND MUSEUM (SIR AUBREY STRAHAN, F.R.S.).—A series of photomicrographs to illustrate the mineralogical constitution and structure of rocks as revealed by the petrological microscope, and specimens to illustrate the mode of preparation of thin rock-sections for microscopical examination.

LIEUT.-COL. WILLIAM GIFFORD.—Monochromatic light filters for use in high-power microscopy and photomicrography. F line for visual work, G for photography.

MESSRS. FLATTERS AND GARNETT, LTD.—Photographs of textile fabrics and fibres.

MR. J. W. GORDON.—Demonstration of the principles of illumination in the microscope, with special reference to:—

1. Wide-angled lighting.
2. Narrow-angled lighting.
3. Wide-angled vision.
4. Narrow-angled vision.

MESSRS. HADFIELDS, LTD.—Photomicrographs of iron and steel.

MR. R. J. E. HANSON, F.R.C.S.—

Dyoptikon (Eye-piece) Headrest.

[Applicable to any existing standard microscope.]

A sliding headrest is provided, with rubber tubular buffer —to lessen fatigue and mal-orientation of the eyes and to secure effective retinal adaptation and stimulation of (R and L) visual cortex.

A Solution of Visual Purple.

DR. H. HARTRIDGE.—

(1) Apertometry by means of the descending light-path.

(2) Water-soluble immersion medium for use with high-power objectives.

(3) Critical illumination with immersion condenser, the light source being attached to and forming part of the microscope.

Dr. W. H. Hatfield.—Photomicrographs illustrating application of microscope to metallurgical work.

Mr. E. Hatschek.—Ultra-filters for retaining ultra-microscopic particles. Collodion membrances are used as septa: according to the method of preparation they may be used with pressure (Bechhold) or they may work with hydrostatic head only (Wo. Ostwald).

Messrs. Hawksley and Sons.—Microscopes by the Spencer Lens Company suitable for research work, students' models, also travelling model in all-metal case. Blood examination apparatus. Thoma-Hawksley haemacytometers with various rulings.

Mr. C. F. Hill and Mr. H. C. Lancaster.—The use of the microscope in the metallography of lead. Typical samples of lead, containing antimony, tin, copper, and zinc. Also a new bearing metal, made of lead, containing calcium and barium.

Miss Nina Hosali.—Models illustrating crystalline form and symmetry.

Messs. Ilford, Ltd. (Mr. F. F. Renwick).—Exhibit arranged to show the range and spectrum of thirty colour filters, including a set of nine micro-filters, eight spectrum (single-band) filters, tricolour filters and their complementaries, mercury vapour lamp filters and photographic correction filters.

Jaeger Laboratory (Mr. A. E. Garrett).—

Exhibit Illustrating the Analysis of Textiles.

The microscope is the final Court of Appeal in the testing of textile materials in so far as the nature of their constituent fibres is concerned.

There is no difficulty in dividing the more generally used fibres into the following distinct classes:—

1. Wool and other animal hairs.
2. Silk.
3. Cotton.
4. Other plant fibres (flax, ramie, jute, etc.).

Classes 1 and 4 are, however, as indicated, subject to much subdivision.

Class 1 contains wool, camel hair, alpaca, vicuna, cashmere, mohair, and a few less well-known hairs. Class 4 contains all the multi-cellular fibres obtained from the stems or leaves of plants, and their number mounts up considerably, especially if those employed for sacking, rope, etc., are included.

The distinguishing features in Class 1 are the diameter of the fibres, the colour of the pigment when present, the distribution of the pigment cells, and scale structure or other surface markings.

In Class 4 the diameter of the fibres, the nature of the cell walls—uniform thickness, etc.—the size of the lumen, and superficial markings help in the recognition of the fibre. Polarised light will often assist in this section.

The microscope can also be used to determine:—

(a) Whether the fibres are in their normal state or have undergone treatment which has altered their shape.

(b) Whether coloured fibres owe their tint to natural pigment or dye. The pigment cells appear as separate units, while the dyed fibres appear of uniform tint throughout.

MESSRS. JEYES' SANITARY COMPOUNDS COMPANY, LTD. (MR. W. C. REYNOLDS, F.I.C.).—Illustrating the theory of emulsions.

MESSRS. KODAK, LTD.—Filters for photomicrography, spectroscopy tri-colour photography, filter-holders and other photomicrographical accessories, plates for photomicrography.

THE PHOTOMICROGRAPHIC SOCIETY.—

MR. F. MARTIN DUNCAN, F.R.M.S., F.R.P.S., F.Z.S.—Prints of low and high power photomicrographs, including bacteria, etc.

DR. G. H. RODMAN, F.R.P.S.—Transparencies of photomicrographs of a variety of subjects, in viewing frame.

MR. E. A. PINCHIN, F.R.M.S.—Transparencies of photomicrographs of diatoms, in viewing frame.

MR. F. IAN G. RAWLINS.—A moderate-sized "ordinary" microscope, modified for use in metallography.

Features:—

(a) Substage arrangement.
(b) Modified objectives (converted to short barrel from standard lenses).
(c) Half-watt lamp, affording sufficient illumination at minimum expense and trouble.

MR. J. RHEINBERG.—Some Applications of:—

(1) Filmless photography.
(2) Grainless photography.
(3) Platinised and semi-platinised surface mirrors.

MR. SYDNEY W. ROSS, F.R.M.S.—A new apparatus for the microscopic examination and photomicrography of metallic specimens (two forms, drawings only).

RESEARCH DEPARTMENT, WOOLWICH.—

(1) Microscope with filar micrometer eye-piece, used for the measurement of small Brinell ball hardness impressions (0.2 to 0.8 millimetre in diameter) to 0.001 millimetre.
(2) Photomicrographs of structures found in gun-steel, shell-steel, etc.

M. EUGENE SCHNEIDER AND M. CHARLES FLORIAN.—A microscope for measuring Brinell depressions. (Constructed by the Société d'Optique et de Mécanique de Haute Precision, Paris.)

SHEFFIELD UNIVERSITY, by kind permission of the Vice-Chancellor, Sir W. H. Hadow (Professor W. Ripper, and Dr. J. O. Arnold, F.R.S.).

Original Specimens Belonging to Sorby.

(1) The following is a description of the Sorby micro-sections:—

Dr. H. C. Sorby's pioneer micro-sections of iron and steel, made in 1863-5.

Lent in 1889, for Dr. Sorby's lifetime, to Professor J. O. Arnold, F.R.S., and bequeathed on Dr. Sorby's

death in 1908 to the Metallurgical Department of tl University of Sheffield.

(Prepared by Dr. H. C. Sorby, F.R.S., at "Broomfield," Sheffield, 1863-5.)

(2) The gold copper series of micro-sections prepared l Professor J. O. Arnold, F.R.S.:—

Pioneer sections made by Professor J. O. Arnol F.R.S., and Mr. Joseph Jefferson in 1893, showi the micrographic influence of small amounts of impu ties on the structure of pure gold and copper, hen the discovery of brittle intercrystalline cements.

These were fully described in *Engineering*, February 7th, 1896.

(3) Framed signed portrait of the late Dr. H. C. Sorb F.R.S.

Professor Alexander Silverman (University of Pittsburgh —A new illuminator for opaque objects. (Exhibited by Mr. S. Akehurst.)

Dr. J. E. Stead, F.R.S.—An improved form of worksh microscope designed by Dr. J. E. Stead and Messrs. J. Swi and Son.

Series of heat-tinted specimens, showing the structure of ph phoretic steels and metals.

Dr. Marie Stopes.—The microscope as applied to coal researc Illustrated by thin sections of coal, showing differences in textu and of plant content.

Mr. J. Strachan.—The use of the microscope in the examin tion of paper-making materials.

(1) A series of slides showing various paper-making fibr including both those in common use and a few unusu fibres used during the war.

(2) A series of slides showing dendritic growths of copp compound in paper, illustrating the application of t microscope to the study of chemical changes taki place in paper after its manufacture.

Messrs. James Swift and Son, Ltd.—Microscopes for met lurgy and mineralogy and apochromatic objectives.

Messrs. Taylor, Taylor and Hobson, Ltd.—

A microscope for measuring the diameters of depressions ma when testing the hardness of metals by the Brinell method.

The magnification is 16 diameters.

A graticule is incorporated enabling diameters up to abo 7 mm. to be measured.

The microscope stands on three feet, one of them being cloven foot, within the notch of which the object is easily centr in the field of the microscope. The other two feet are adjustable u and down by means of a knurled nut.

The focal plane of the microscope coincides at all times with that of the underside of the cloven foot, so that no focussing is necessary.

The optical system is contained in a single tube, and may be removed as a separate unit. The field and object glasses and the graticule are held in the tube by a novel and very simple means (patented) without screws.

Accuracy of the instrument is guaranteed within .01 mm.

MESSRS. W. WATSON AND SONS, LTD.—Microscopes, objectives and accessory apparatus.

APPENDIX II.

THE WORK OF THE FARADAY SOCIETY,

And a brief reference to Michael Faraday,

BY THE PRESIDENT OF THE FARADAY SOCIETY

(SIR ROBERT HADFIELD, Bart., D.Sc., D.Met., F.R.S.)

As in addition to our own Members, we have a large number of visitors present to-day, I thought it would be of interest to write a short account of the work of our Society, which takes its name from one of the greatest of the Scientific Immortals—Michael Faraday. I need hardly say how glad we shall be to receive an access to our Membership of those interested in the work we are trying to accomplish, which is not only that of covering certain ground not dealt with by other Scientific Societies, but also of arousing interest in the minds of the younger men in our great Metropolis and elsewhere with regard to Scientific developments.

I also take this opportunity of saying a few words about Faraday, who devoted his life to Science, with but one single aim—to advance its position in the world, and to benefit Mankind without fear or favour to rich and poor alike. No monetary or selfish considerations ever entered his mind.

At the time I accepted the invitation of the Council in 1914, conveyed through my friend, Professor A. K. Huntington, to be your President, I was not in good health, and the duties seemed to be far too great for me to undertake. I felt, however, that it was a special honour and privilege to be asked to follow in the footsteps of some of our great Masters of the Past—Kelvin, Swan, and others—so I accepted.

When delivering my Presidential Address in June, 1914, I little dreamt that our Empire was so soon to pass through a time of unexampled stress. Notwithstanding the difficulties with which those five troublous years were surrounded, I am glad to say our work never relaxed, and I do not think we suspended a single meeting, Council, Committee, or General. Thanks to the willing help given on all hands, whether by the Council, by the Members, or by our Secretary, Mr. F. S. Spiers, it has given me no little satisfaction to think that the younger men amongst us have been aided in their work by our Society and its gatherings.

My work with the Faraday Society has been a labour of love. The time is, however, coming when I am sure you must think it only right that another of your Members should take my place as President. Let me add that I have only been too glad to give any help in my power, and its future will always have the warmest interest of my heart.

Our Society owed its origin in 1902, chiefly to a little band of workers who met together to advance the great cause of Scientific Knowledge. It was founded on February 4th, 1903, at a meeting in the rooms of the now defunct Faraday Club, held at St. Ermin's Hotel, Westminster. Amongst its founders were Mr. Sherard Cowper-Coles, Mr. W. R. Cooper, Professor F. G. Donnan, Dr. F. M. Perkin, Mr. Alexander Siemens, Mr. James Swinburne, and Mr. F. S. Spiers, our present Secretary, to whom we owe a deep debt of gratitude for his indefatigable work on behalf of our Society, and to whom there should be accorded a crown of laurels. To each of these Founders I have sent a special invitation asking them to be present this evening.

Our first President was Sir Joseph Swan, F.R.S., later Lord Kelvin, followed by Sir William Perkin, F.R.S., Sir Oliver Lodge, F.R.S., Mr. J. Swinburne, F.R.S., and Sir R. T. Glazebrook, F.R.S., whose portraits are given in the accompanying plate. The objects of the Society as originally defined were to promote the study of Electro-chemistry, Electrometallurgy, Physical Chemistry, Metallography, and kindred subjects.

I venture to think that we are accomplishing the objects for which its founders set out, and that the Faraday Society will continue to increase and flourish. It is, however, very desirable that we should extend our Membership, and I trust a great effort will be made by every present Member to bring in at least another new Member, also that many of our Visitors to-night will join our Roll Call. Stagnation in any Society means final decay. If we fulfil a useful purpose, as we undoubtedly do, then the aim I have set forth of a large increase in Membership ought to be possible. In one important Technical Society in America, I learn they have this year increased their Roll Call by no less than one thousand new Members.

Our Society is honoured and recognised in the Councils of the larger and parent Societies. It has a seat on the Conjoint Board of Scientific Societies and is consulted along with other Societies on the special subjects with which we deal and are acquainted. The fact that the Royal Society has this evening granted us the privilege of holding our Symposium in its historic building also shows, I venture to think, that our work meets with the approval of this great parent body of Scientists.

Nitrogen Products Committee.—I will refer to one subject in which we gave a helping hand during the War—in fact it might be said that the Faraday Society originated this special Research in this Country, namely, that relating to Nitrogen Products, which mainly through our suggestion was taken up by the Munitions Inventions Board. My friend, Professor Huntington, of King's College, worked in season and out of season to get the Government Department concerned interested. He finally succeeded in persuading the Munitions Inventions Department to appoint a Special Nitrogen Products Committee, who in their turn were instrumental in establishing a Research Department. As Mr. H. W. Dickinson, Secretary of the M.I.D., points out, so much spade work was done by the Department with regard to this subject that

when at a later date owing to the submarine campaign the policy of the Ministry changed and it was decided to go to new sources for Nitrogen supply, the results of the research work and of the information gathered by the Research Department mentioned were ready to hand and enabled practical work on a large experimental scale to be commenced at once.

It should be added that the work was taken up for the Committee by one of our Members of Council, Dr. J. A. Harker, F.R.S., who was allowed by the National Physical Laboratory to assist in this important development, his labours being of the highest value. The Country is greatly indebted to him for the untiring devotion he has shown in working out this special and important subject to a successful issue. Our Council hope that before long they will be able to present a Report to us describing in detail the work carried out. The Report of the Committee itself is shortly to be published, and it will probably be one of the most remarkable documents in regard both to scope and matter that has been issued by a Government Department during those troublous times.

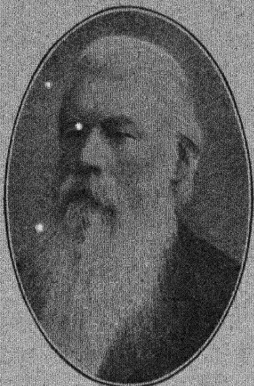
The work done, although not immediately made use of for War purposes, as the Armistice rendered any help needless in this quarter, will, without doubt, bear great fruit in the future; in fact, the Nitrogen Factory, which was being started during the War, has already been taken over by a private organisation. It is therefore probable that the Nitric Acid required in this Country for making explosives, dyes and drugs will be produced synthetically in this manner.

Symposia previously held.—Since the formation of the Faraday Society, we have had approximately 330 papers presented to us, most of them fully discussed. During my own term of office—1914 to 1919—some 180 papers have been read, and, including the present one, there have been fifteen Symposia held, attended by considerably over 3,000 Members and Visitors. The following shows these in tabular form:—

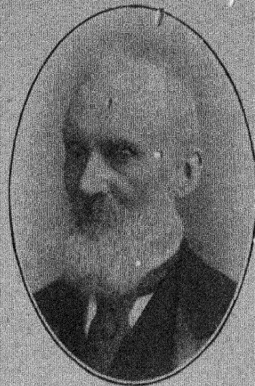
No.	Date.	Title.
1	Nov., 1914	The Hardening of Metals.
2	Oct., 1915	The Transformations of Pure Iron.
3	Dec., 1915	The Corrosion of Metals.
4	Mar., 1916	Methods and Appliances for the Attainment of High Temperatures in the Laboratory.
5	Nov., 1916	Refractory Materials.
6	Mar., 1917	The Training and Work of the Chemical Engineer
7	May, 1917	Osmotic Pressure.
8	Nov., 1917	Pyrometers and Pyrometry.
9	Jan., 1918	The Setting of Cements and Plasters.
10	Feb., 1918	Electric Furnaces. (Symposium at Manchester.)
11	May, 1918	The Co-ordination of Scientific Publication.
12	Nov., 1918	The Occlusion of Gases by Metals.
13	Jan., 1919	The Present Position of the Theory of Ionisation.
14	April, 1919	Radiometallography.

THE FARADAY SOCIETY

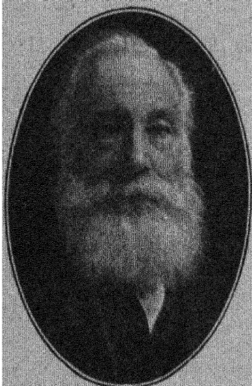
and six of its Past Presidents.



Sir JOSEPH SWAN
(First President)
1903–1904



Lord KELVIN
(Second President)
1905–1907



Sir WILLIAM PERKIN
1907–1908

MICHAEL FARADAY
1791–1867

Sir OLIVER LODGE
1908–1909

JAMES SWINBURNE
1910–1911

Sir RICHARD GLAZEBROOK

It is hoped that the present Symposium will be no less successful than previous ones. Many Members and others at home and abroad have expressed their thanks for the useful work done by our Society. We have also tried to give a helping hand and encouragement to the younger men in our midst. This has been one of the chief objects we have always had specially in mind. Let our motto be "Thoroughness," and we shall continue to flourish and do still better work in the future.

The Work of Michael Faraday.—Turning now for a moment to Michael Faraday, from whom our Society takes its name, I will a little later on refer to one of the descriptions of the Great Scientist, by Professor John Tyndall, F.R.S., in his lecture before the Royal Institution in January, 1868, on "Faraday as a Discoverer."

De la Rive, the well-known French Scientist in his "Notice on Faraday's Life and Work," Archives des Sciences de la Bibliothèque Universelle, October, 1867, stated that the number of Faraday's Memoirs from 1820 to 1855, all of these important, was almost incredible.

Faraday was born at Newington Butts on the 22nd September, 1791, and finally passed away at Hampton Court on the 25th August, 1867.

Tyndall said that it seemed desirable to give the world some image of Michael Faraday as a scientific investigator and discoverer. He regarded the attempt to respond to this desire, whilst a labour of difficulty in adequately presenting a history of this great man, as also a labour of love. However well acquainted he might be with the researches and discoveries of the great master—however numerous the illustrations which occur to him of the loftiness of Faraday's character and the beauty of his life—still to grasp him and his researches as a whole; to seize upon the ideas which guided him and connect them; to gain entrance into that strong and active brain and read from it the riddle of the world—was a work not easy of performance. As he was a believer in the general truth of the doctrine of hereditary transmission, Tyndall, who shared the opinion of Carlyle that a really able man never proceeded from entirely stupid parents—said that he once used the privilege of his intimacy with Faraday to ask him whether his parents showed any signs of unusual ability. He could remember none. His father was a great sufferer during the later years of his life, and this might have masked whatever intellectual power he possessed. When thirteen years old, that is to say in 1804, Faraday was apprenticed to a book-binder in Blandford Street, Manchester Square; here he spent eight years of his life, after which he worked as a journeyman elsewhere.

Faraday was only 22 years of age when he obtained a position in the Royal Institution. His first contribution to Science appeared in the Journal of the Royal Institution in 1816, that is, in the publication known as the "Quarterly Journal of Science." I thought it might be of interest to give the following summaries by Tyndall of (1) Researches by Faraday, and (2) Discoveries by Faraday:—

RESEARCHES BY FARADAY.

	PUBLISHED.
First contribution to Science—Analysis of Caustic Lime from Tuscany	1816
Experiments on Sounding Flames	1818
Vaporisation of Mercury at Ordinary Temperatures	1821
On the Limits of Vaporisation	
Experiments on Alloys of Steel	
Vibrating Surfaces	1829
On the Quantitative Comparison of different forms of Electricity	1833
On the Absolute Quantity of Electricity associated with the particles or Atoms of Matter	
The Power of Metals and other Solids to induce the combination of gaseous Bodies	
Extra Current—The influence by induction of an Electric Current upon itself	1835
On Frictional Electricity, Induction, Conduction, Specific Conductive Capacity, and Theory of Contiguous Particles	1835 to 1838
Further Researches on Liquefaction of Gases—Establishing the fact that Gases are vapours of Liquids possessing very low boiling points	1844
Speculations on the Nature of Matter and Lines of Force ...	1846
On the Diamagnetic Condition of Flame and Gases	1847
On Magne Crystallic Action and Lines of Force ...	1848 to 1851
Magnetism of Gases	1850
Atmospheric Magnetism	
Electricity of Gymnotus	
Source of Power of the Hydro-Electric Machine	
Regelation	

DISCOVERIES BY FARADAY.

	PUBLISHED
Two new Compounds—Chlorine, Carbon and Iodine; Carbon and Hydrogen	1820
Alloys of Steel	1821
Magnetic Rotations	
Liquefaction of Gases	1823
Change of colour of Glass in Sunlight	1825
New Compounds of Hydrogen and Carbon	1826
Benzol	
Improvements in manufacture of Glass for Optical purposes. Afterwards the foundation of most important Discoveries, *e.g.*, Magnetisation of Light	1829
Peculiar class of optical deceptions—optical toy, the Chromotrope owed its origin to this	
Magneto-Electric Induction—Tyndall says: "Greatest experimental result ever obtained by an investigator. The 'Mont Blanc' of Faraday's achievements"...	
Terrestrial Magneto-Electric Induction	
Identities of Electricities—Static, Voltaic, Magneto, Thermo, etc.	1833
New Law of Electric Induction	
Laws of Electro-Chemical Decomposition—Definite Electro-Chemical Decomposition. Tyndall says: "This Law ranks in importance with that of the Definite Combining Proportions in Chemistry"	
Origin of Power in the Voltaic Pile	1834
Magnetisation of Light and the Illumination of the Lines of Magnetic Force. In other words, the Rotation of the Plane of Polarisation	1845
Diamagnetism or the Magnetic Condition of all Matter	
Atmospheric Magnetism	1850

SUMMARY OF FARADAY'S WORK.[1]

I will also quote Tyndall's Summary of Faraday's work somewhat fully as it is indeed worth reading. It is a stimulus to each of us according to his light to go and try to do likewise, even if in a smaller and humbler way.

Tyndall says:

"When from an Alpine height the eye of the climber ranges over the mountains, he finds that for the most part they resolve themselves into direct groups, each consisting of a dominant mass surrounded by peaks of lesser elevation. The power which lifted the mightier eminences, in nearly all cases, lifted others to an almost equal height. And so it is with the discoveries of Faraday. As a general rule, the dominant result does not stand alone, but forms the culminating point of a vast and varied mass of enquiry.

In this way, round about his great discovery of Magneto-Electric Induction, other weighty labours grouped themselves. His investigations on the Extra Current; on the Polar and other conditions of Diamagnetic Bodies; on Lines of Magnetic Force, their definite character and distribution; on the employment of the Induced Magneto Electric Current as a measure and test of Magnetic Action; on the Repulsive Phenomena of the Magnetic Field, are all, notwithstanding the diversity of title, researches in the domain of Magneto-Electric Induction.

Faraday's second group of Researches and Discoveries embraced the chemical phenomena of the current. The dominant result here is the great Law of Definite Electro-Chemical Decomposition, around which are massed various Researches on Electro-Chemical Conduction and on Electrolysis both with the Machine and with the Pile. To this group also belong his Analysis of the Contact Theory; his Inquiries as to the Source of Voltaic Electricity, and his final development of the Chemical Theory of the Voltaic Pile.

His third great discovery is the Magnetisation of Light, which may be likened to the Weisshorn among mountains—high, beautiful and alone.

The dominant result of his fourth group of Researches is the discovery of Diamagnetism, announced in his Memoir as the Magnetic Condition of all Matter, round which are grouped his enquiries on the Magnetism of Flame and Gases; on Magne-Crystallic Action and on Atmospheric Magnetism, in its relation to the annual and diurnal variation of the needle, the full significance of which is still to be shown.

These are Faraday's most massive discoveries, and upon them his fame must mainly rest. But even without them, sufficient would remain to secure for him a high and lasting scientific reputation. We should still have his Researches on the Liquefaction of Gases; on Frictional Electricity; on the Electricity of the Gymnotus; on the Source of Power in the Hydro-Electric Machine; on the Electro

Magnetic Rotations; on Regelation; all his more purely Chemical Researches, including his discovery of Benzol. Besides these he published a multitude of minor papers, most of which in the same way illustrate his genius."

Tyndall adds that no allusion is here made to his power as a Lecturer. Taking him all in all, it will be conceded that Michael Faraday was probably the greatest experimental Philosopher the world has ever seen. The progress of future research will tend not to dim or diminish, but to enhance and glorify the labours of this mighty investigator.

Speaking with regard to my own lines of research, as representing the Faculty of Metallurgy, I may mention that Faraday in his experiments on Alloys of Iron with other Elements, in other words the production of Alloy Steel, carried out in 1821 and 1822 showed that a remarkable inspiration evidently existed in his mind as to the great future this line of research work presented. Singular to say it is just about 100 years ago that Faraday wrote several letters from the Royal Institution (in April and June, 1820) to his Swiss friend De la Rive, Professor of Chemistry, Geneva, in which he gave an account of some experiments on Steel made by himself and Stodart. The world's great technical advances during the last thirty years have been—and I say it unhesitatingly—in a large measure due to the introduction of Alloy Steels such as Faraday had in mind. As already mentioned, Faraday with Stodart, started these researches at the Royal Institution finally completing the experiments by sending his various mixtures to be melted at the Sanderson Works in Sheffield, this Firm being still in existence to-day. The specimens had to be sent by coach, the work being given to a trusty assistant who had to go down and see the experiments put in hand and completed. Beyond the work of Mushet this particular land of Research lay fallow for many years, in fact it was my own discovery and invention of Manganese Steel in 1882 which showed that the new world already indicated by Faraday was there ready to be explored. This exploration has rapidly taken place during the last thirty years, including the discovery and invention of Chromium Steel, Silicon Steel, Nickel Steel, Tungsten Steel, High-speed Tool Steel, Non-corroding, and many other types of Steels.

Almost as important was the fact that Alloy Steel necessitated special heat treatment, which again required and called for the use of scientific methods for the determination of temperatures, critical points, microstructure study, improved analytical methods, mechanical testing, hardness determination, observation of electrical conductivity, magnetic susceptibility, electrical resistance, hysteresis effects and other qualities.

In conclusion, this Society is indeed honoured in being allowed to bear the name of so great a man as Faraday, whose work is still benefiting our Empire.